Linear Colliders
The ILC Project

Seminar
University Mainz, 2.7.2014
Ties Behnke, DESY

Personal Information

Education:

- Study of Physics in Würzburg: 1980-1983
- Master of Art (Physics) at the State University of New York, Stony Brook: 1984
- PhD from SUNY Stony Brook: 1989

- CERN fellow: 1989-1991
- Postdoc Uni Hamburg/ DESY: 1991-1995

- Tenured CERN staff: 1995-1998
- DESY leading scientist: 1998 – today
- Guest scientists at SLAC (Stanford) 2002/ 2003

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DESY summer student 1992
Laboratory student: 1983/ 84

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Responsible for a group of 2 postdocs and up to 4 students

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Crystall Ball Experiment at DESY

DESY summer student Laboratory student: 1983/ 84

D0 Experiment at Fermilab

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OPAL Experiment at CERN

responsible for a group of postdocs and up to 4 students

TESLA at DESY/ HERA/ LEP

- Tenured CERN staff: 1
- DESY leading scientist: 1998 – today
- Guest scientists at SLAC (2003

E133 at SLAC

ILC/ ILD/ DetDev

Linear Colliders
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- The case for lepton colliders
- Challenges
- Experimentation at the ILC
- Opportunities in Japan

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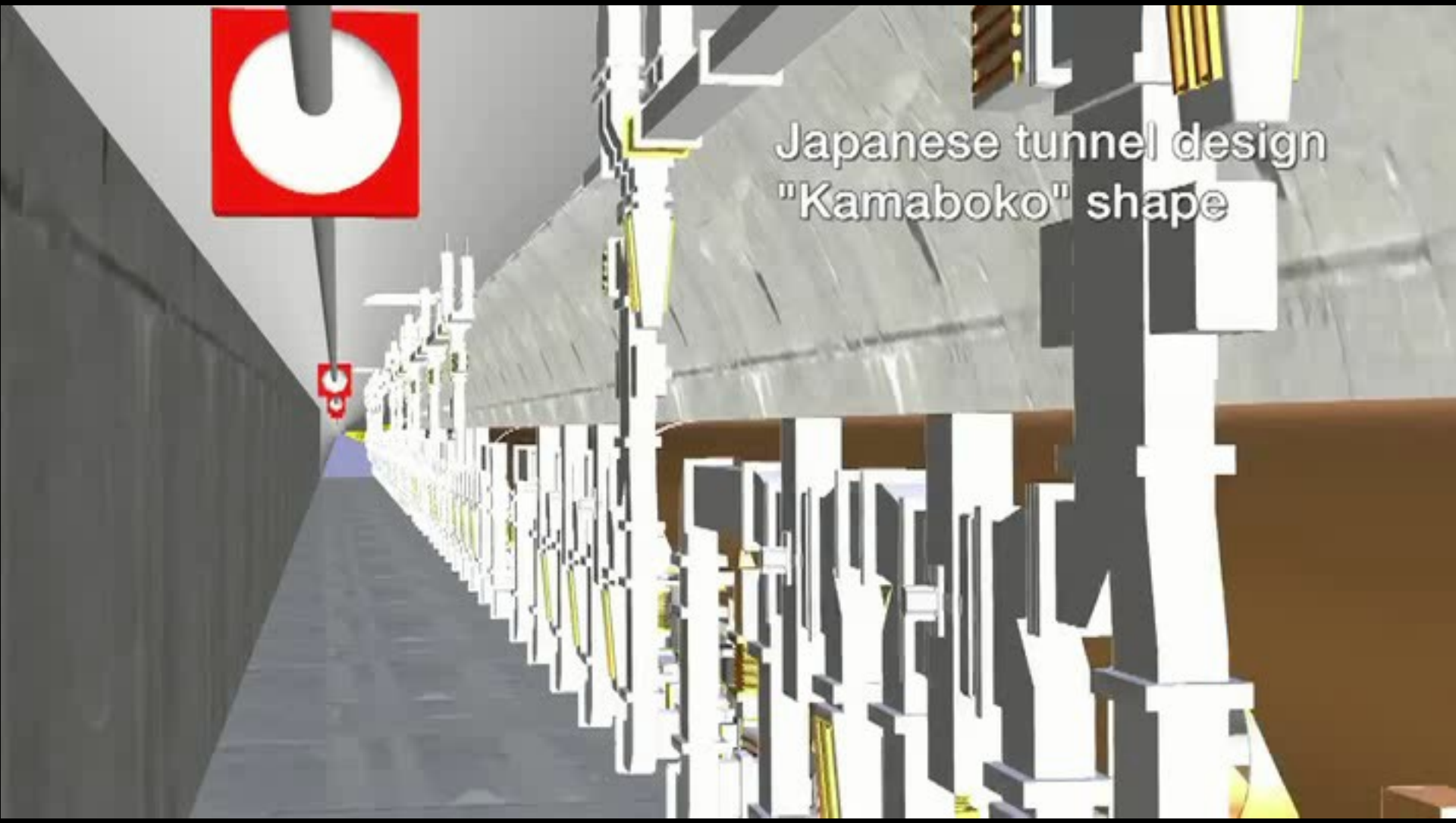
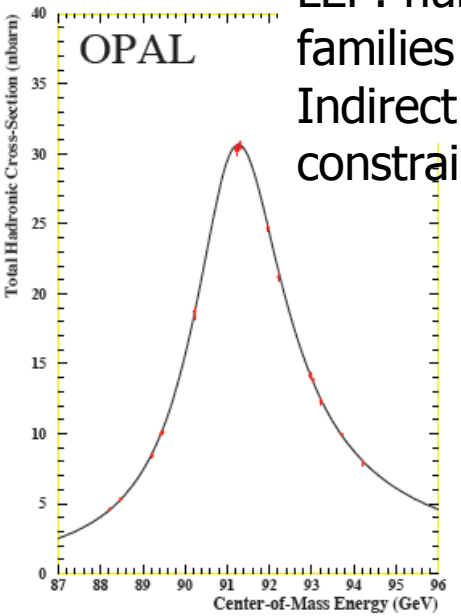
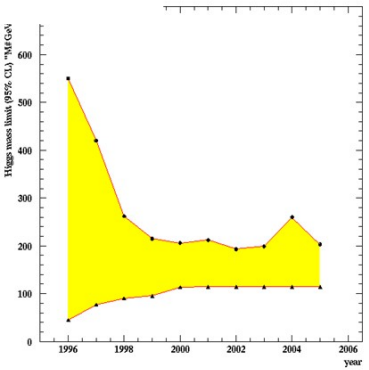
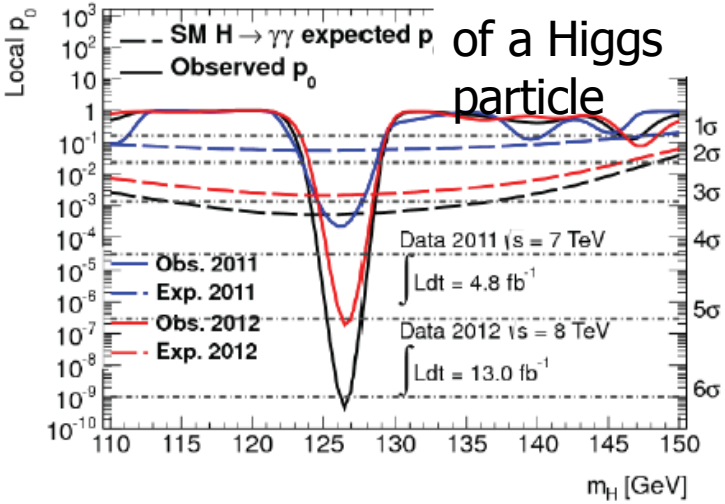

Japanese tunnel design
"Kamaboko" shape

The success of the Standard Model: Predictability



LEP: number of families
Indirect constraints





LHC: discovery of a Higgs particle

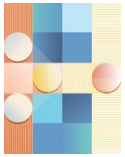
Many effects which are outside the scope of the Standard Model:

- dark matter
- baryogenesis
- quantum numbers of quarks and leptons
- neutrino mass
- dark energy and cosmic inflation
- ...

Theoretical ideas:

- Supersymmetry
- Extra Dimensions
- Compositness
- ...

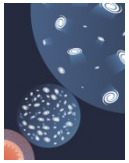
Key Challenges



1. Use the Higgs Boson as a new tool for discovery

1. Pursue the physics associated with neutrino mass

2. Identify the new physics of dark matter



3. Understand cosmic acceleration: dark energy and inflation

4. Explore the unknown: new particles, interactions, and physical principles

Key Challenges

1. Use the Higgs Boson as a new tool for discovery

1. trino mass

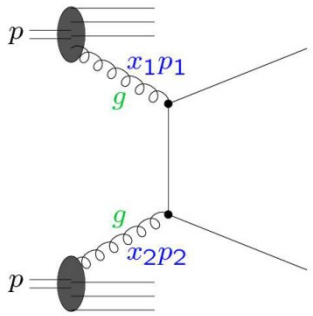
Accelerator based
experiments
can contribute significantly
to all of these questions!

ergy and

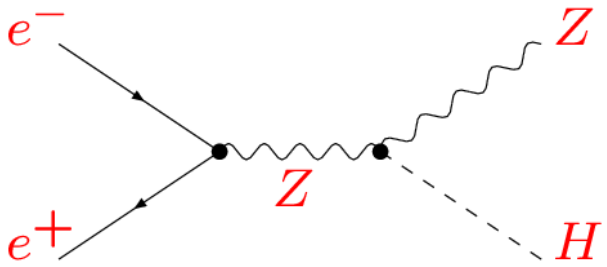
4. Explore the unknown: new particles, interactions, and physical principles

Lepton Collisions as the way into the Future

LHC: pp scattering
at <= 14 TeV



LC: e+e– scattering
at <= 1 TeV (3 TeV)



Scattering process of proton constituents with energy up to several TeV,
strongly interacting

huge QCD backgrounds,
low signal–to–backgr. ratios

Clean exp. environment:
well-defined initial state,
tuneable energy,
beam polarization, GigaZ,
□□, e□, e–e– options, . . .

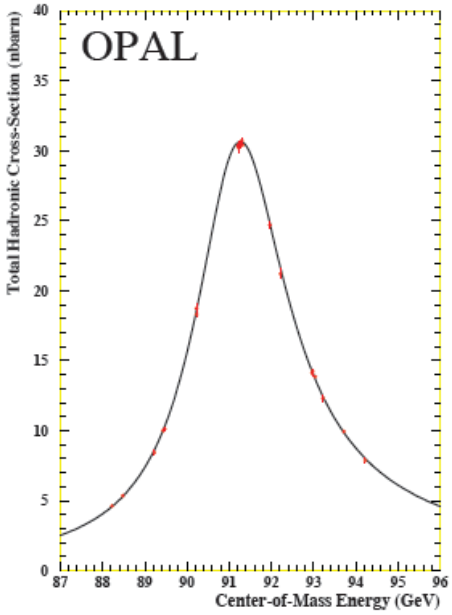
rel. small backgrounds

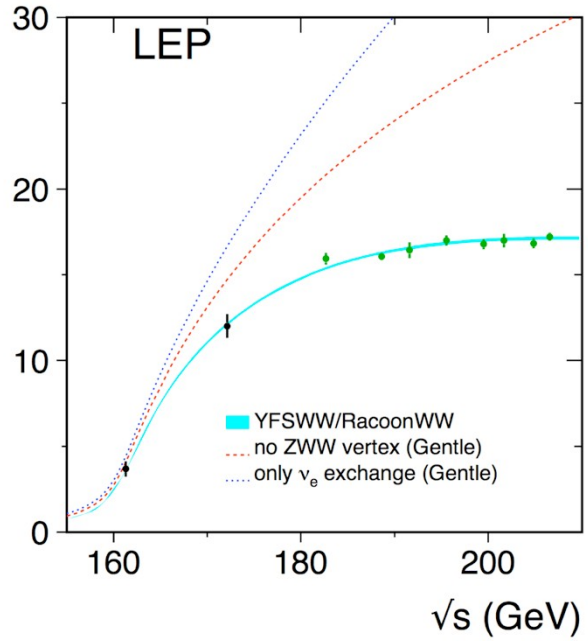
Lepton Colliders

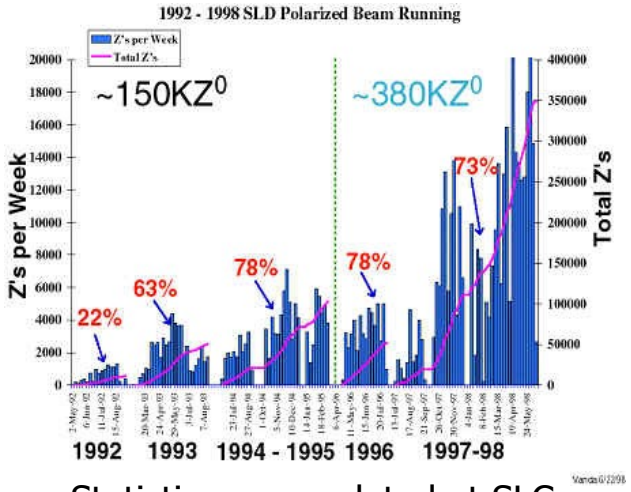
LEP

Long history of successful lepton colliders at the energy frontier:

- Last high energy colliders: SLC at SLAC, until 1998,
  LEP at CERN, until 2000







Statistics accumulated at SLC, the worlds only linear collider so

The Physics Agenda at the Energy Frontier

Explore the physics at the scale of electroweak symmetry breaking

- Higgs Physics
- Standard Model Physics at "Terascale"

Physics beyond the Standard Model

- Search for new physics (Supersymmetry, ...)
- Explore the Terascale

Follow up on any discoveries the LHC might have made

What do we need?

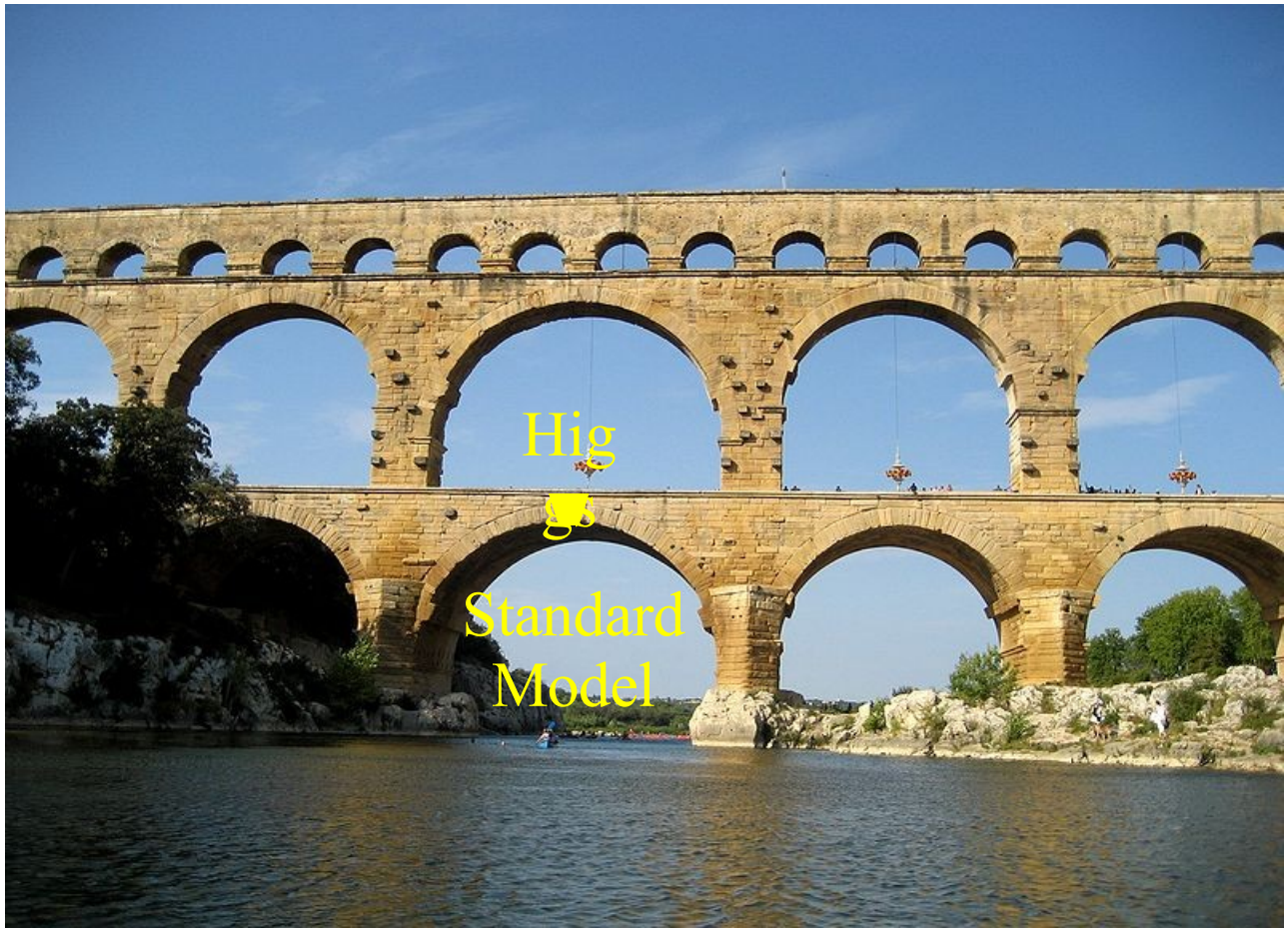
1. Precision: strong case for electron positron collisions
   - Precision reconstruction of Higgs properties
   - Precision reconstruction of top properties

2. Full Higgs programme: need energy reach up to about 1 TeV
   - Branching ratios (250 GeV)
   - Top coupling (350 GeV)
   - Coupling to Top (ttH) (550 GeV)
   - Self coupling (1 TeV)

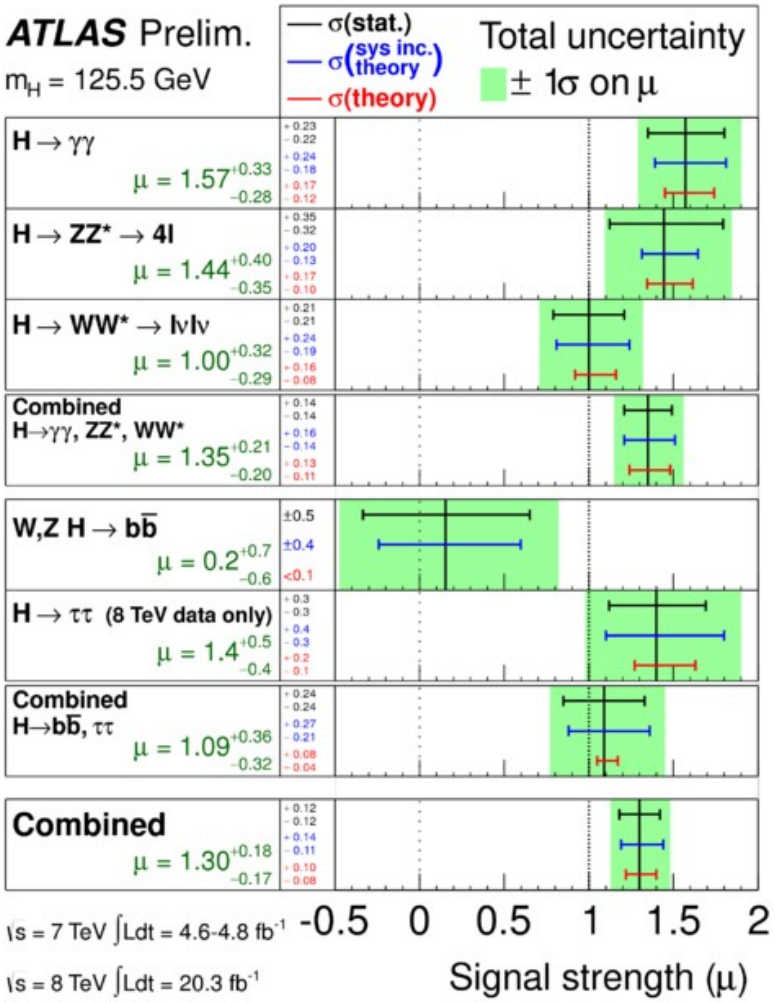
3. Strong case for linear machine
   - Energy reach

Strong physics case for an electron positron collider with E(cms) up to 1 TeV

Higgs: Keystone of Standard Model



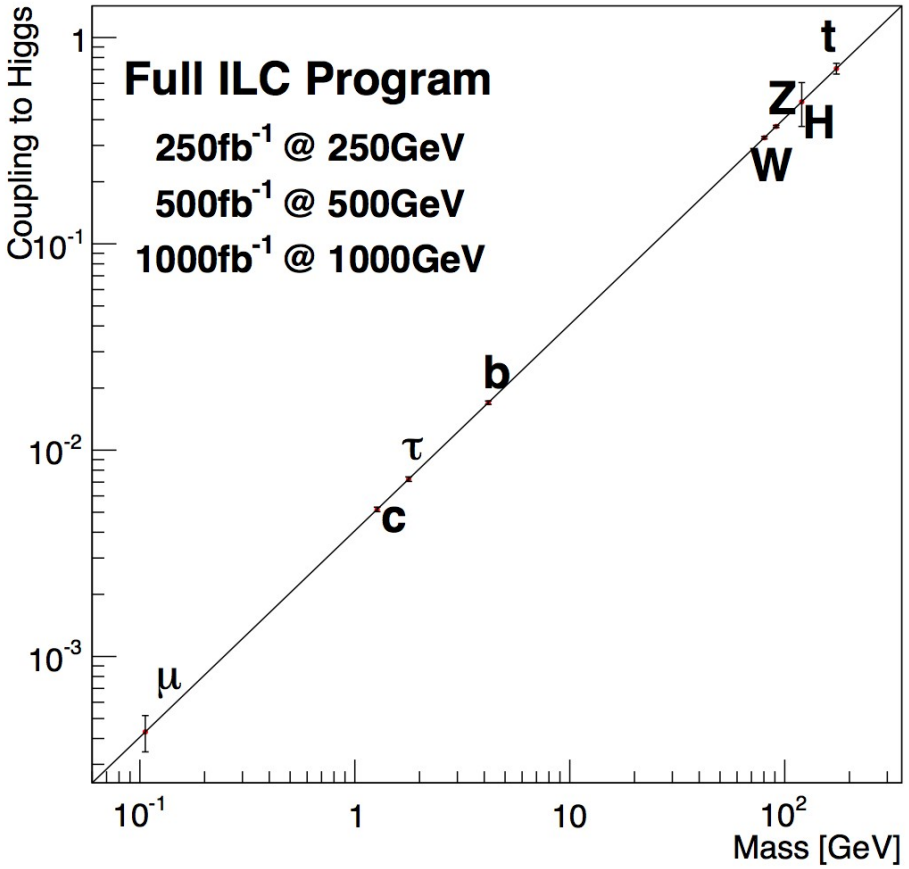
The Higgs: What do we know



- We have seen a Higgs like state
- Its known parameters so far are compatible with a SM Higgs
- We are sure to see this particle
  in pp and in electron positron

  (since it couples to WW, ZZ)

Higgs Physics: what we want



Comprehensive study of the Higgs

Couplings

- Multi Jets in the final state
- need excellent jet-energy resolution to get decent measurement

Precision needed

Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$< 1.5\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

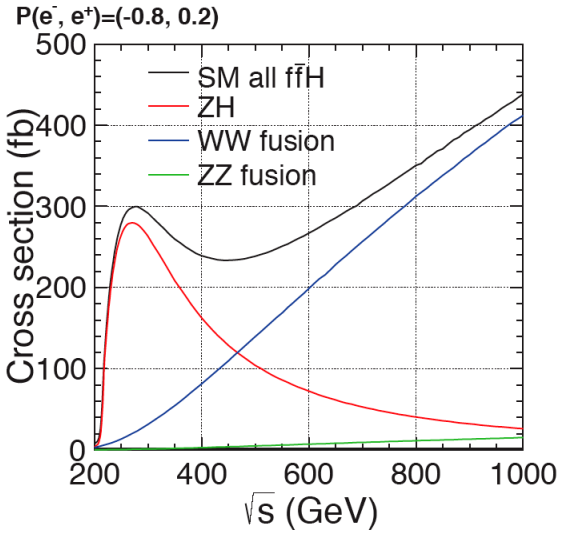
2013 snowmass study, energy frontier report

Deviations from SM couplings are typically a few percent.

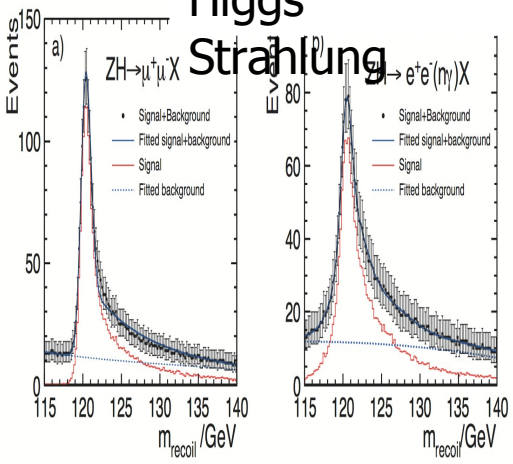
Discovery means 5σ, so need sub-percent accuracy

Higgs Physics

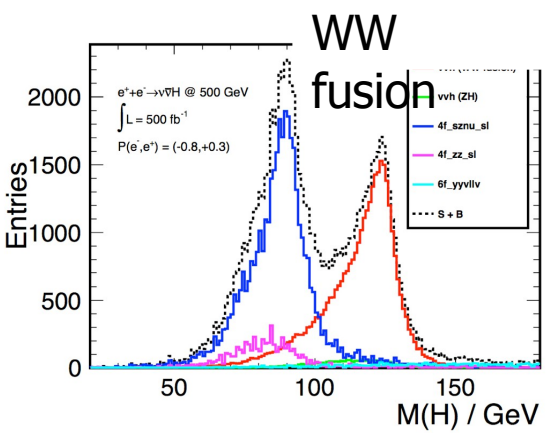
Higgs signals at ILC are very clean:



Higgs Strahlung



WW fusion



Higgs recoil measurement (absolute width):

~ 235–260 GeV

(90+125+20 GeV)

Higgs branching ratios and tt threshold:

350 GeV = 2*175 GeV

Htt coupling, top physics, Higgs self coupling:

≥ 500 GeV – 1000 GeV

(tth threshold:

2*175+125 = **475GeV,**

550 GeV for best rates)

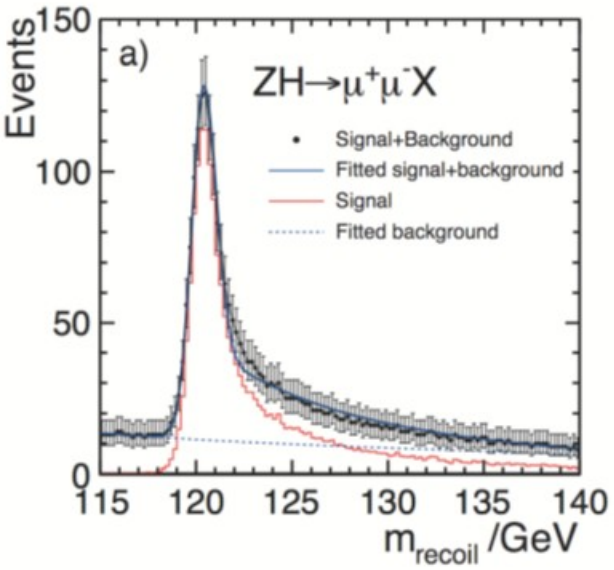
What do we measure?

ILC and LHC: observe Higgs in specific decay mode: σ X BR

Production cross section:

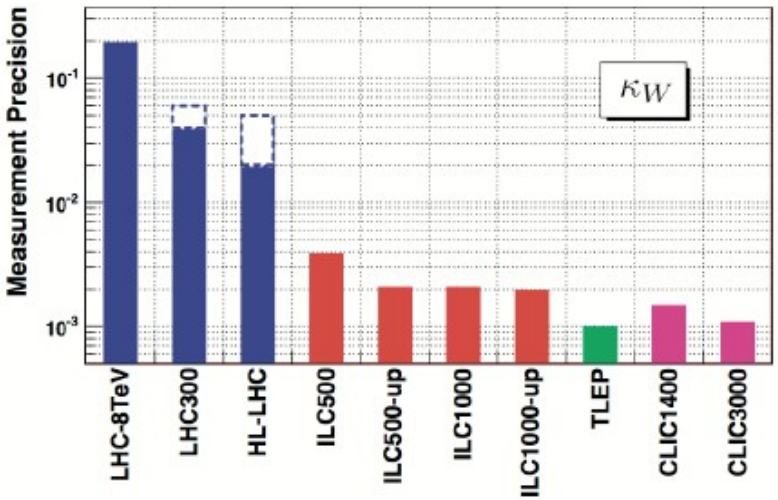
- Very difficult to measure at the LHC
- Precision measurements possible at the ILC (Higgs Recoil Method)

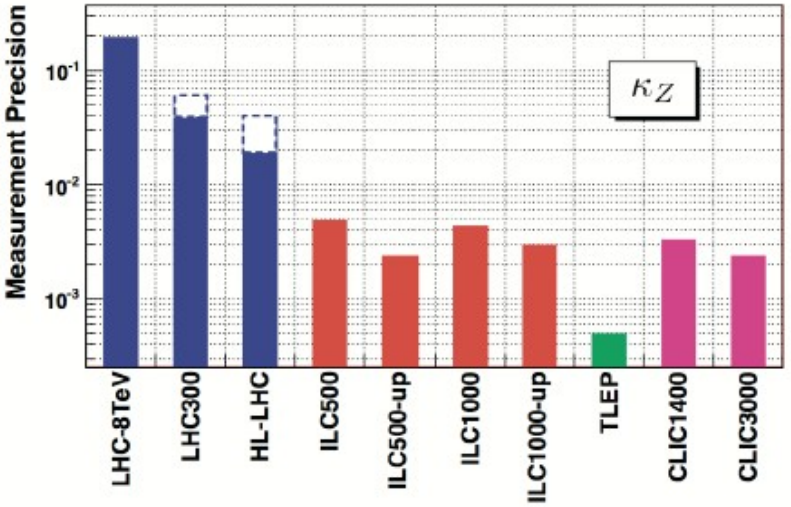
Only the ILC can provide a model independent measurement of the branching ratios!

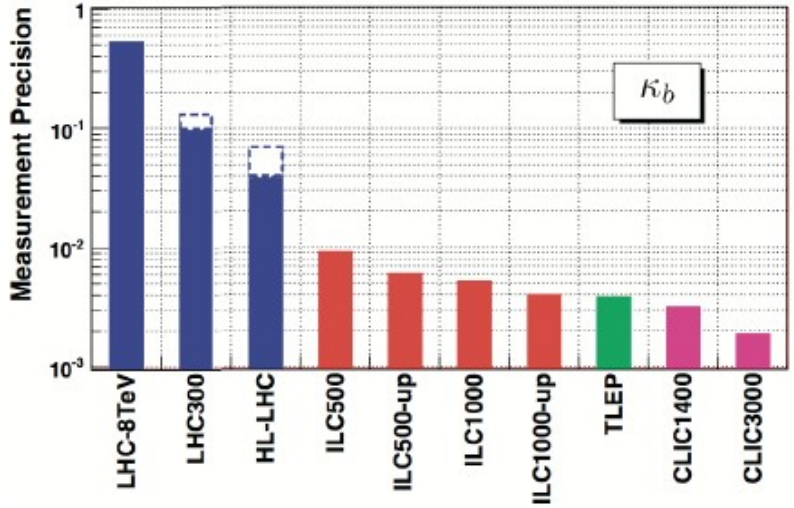


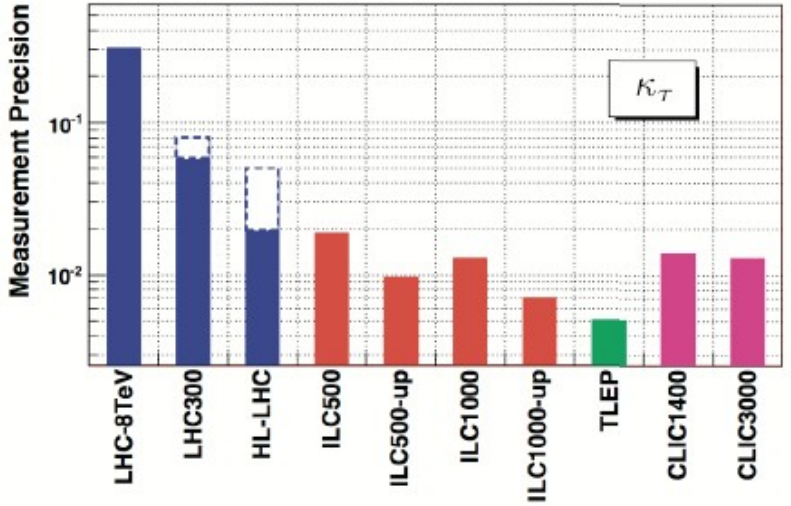
Mass spectrum for Recoil analysis at 500 GeV

Results









Snowmass Higgs report

A word on numbers

When comparing results great care is needed to compare things on an equal footing.

The goal should be to be as model independent as necessary.

The impact on the results can be huge:

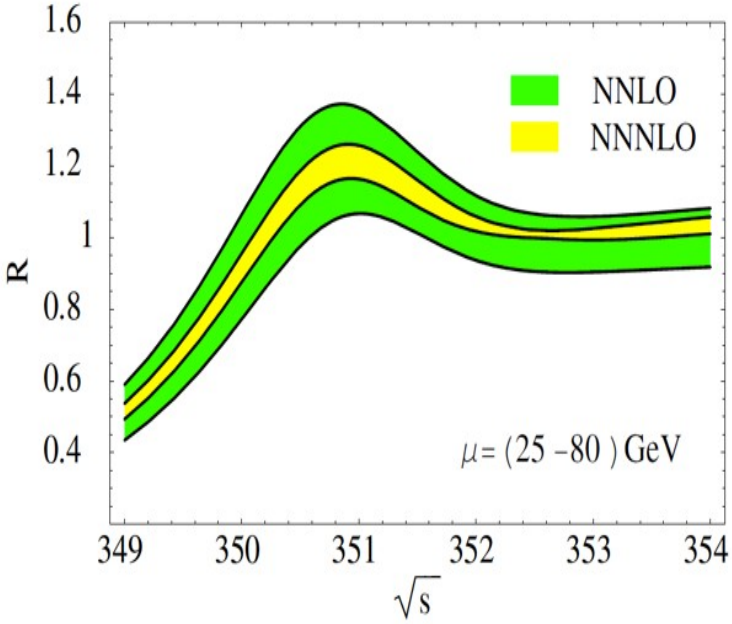
error in Γ_T	unconstrained	$\sum BR = 1$
ILC 500	5.0%	1.6%
ILC 500 up	2.8%	0.75%
ILC 1000	4.6%	1.2%

ILC Higgs Program

Energy	Reaction	Physics Goal	Polarization
91 GeV	$e^+e^- \to Z$	ultra-precision electroweak	A
160 GeV	$e^+e^- \to WW$	ultra-precision W mass	H
250 GeV	$e^+e^- \to Zh$	precision Higgs couplings	H
350–400 GeV	$e^+e^- \to t\bar{t}$	top quark mass and couplings	A
	$e^+e^- \to WW$	precision W couplings	H
	$e^+e^- \to \nu\bar{\nu}h$	precision Higgs couplings	L
500 GeV	$e^+e^- \to f\bar{f}$	precision search for Z'	A
	$e^+e^- \to t\bar{t}h$	Higgs coupling to top	H
	$e^+e^- \to Zhh$	Higgs self-coupling	H
	$e^+e^- \to \tilde{\chi}\tilde{\chi}$	search for supersymmetry	B
	$e^+e^- \to AH, H^+H^-$	search for extended Higgs states	B
700–1000 GeV	$e^+e^- \to \nu\bar{\nu}hh$	Higgs self-coupling	L
	$e^+e^- \to \nu\bar{\nu}VV$	composite Higgs sector	L
	$e^+e^- \to \nu\bar{\nu}t\bar{t}$	composite Higgs and top	L
	$e^+e^- \to \tilde{t}\tilde{t}^*$	search for supersymmetry	B

Top at the Linear Collider

- Top mass: Fundamental SM parameter, leading contribution to radiative corrections
- Threshold scan measures mass in a theoretically very clean way
  ☐ gets rid of QCD uncertainties (~1 GeV) present in all measurements that sum up final state mass
- Important input for radiative correction measurements!



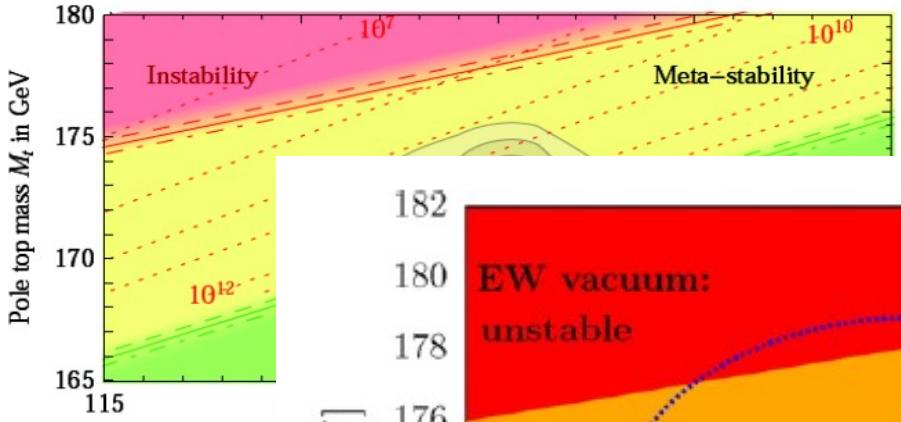
→ tests new physics

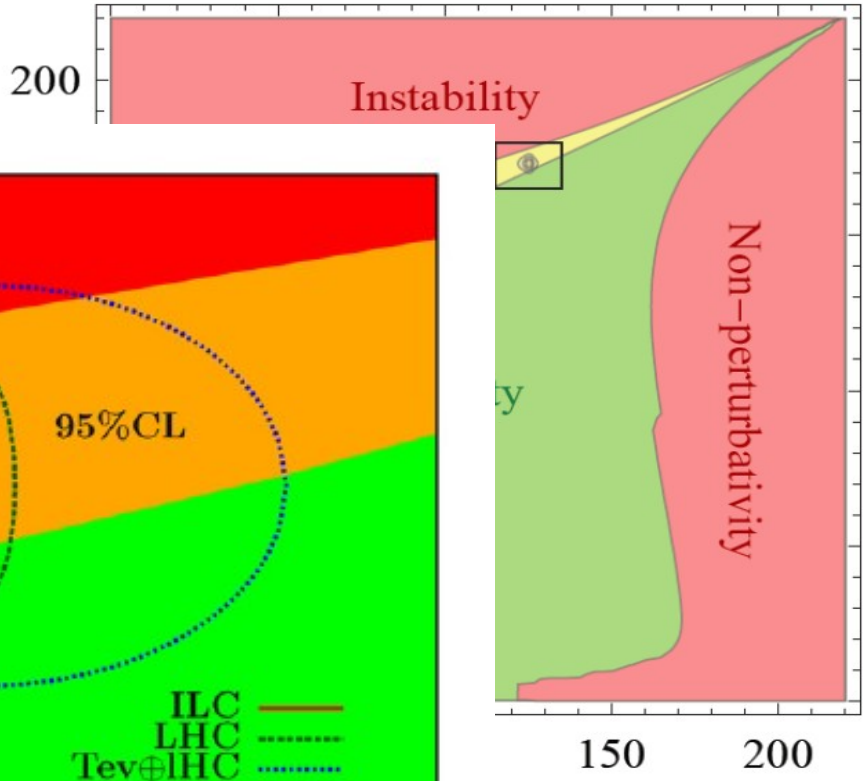
Top performance:
Mass*: 27MeV (0.019%)
Width: 22MeV (1.7%)

* Recent study (F. Simon, ALCPG'12)

How important is the top mass measurement?

[Degrassi, Di Vita, Elias-Miro,Spinosa,Giudici '12,
Alekhin, Djouadi, Moch '12]





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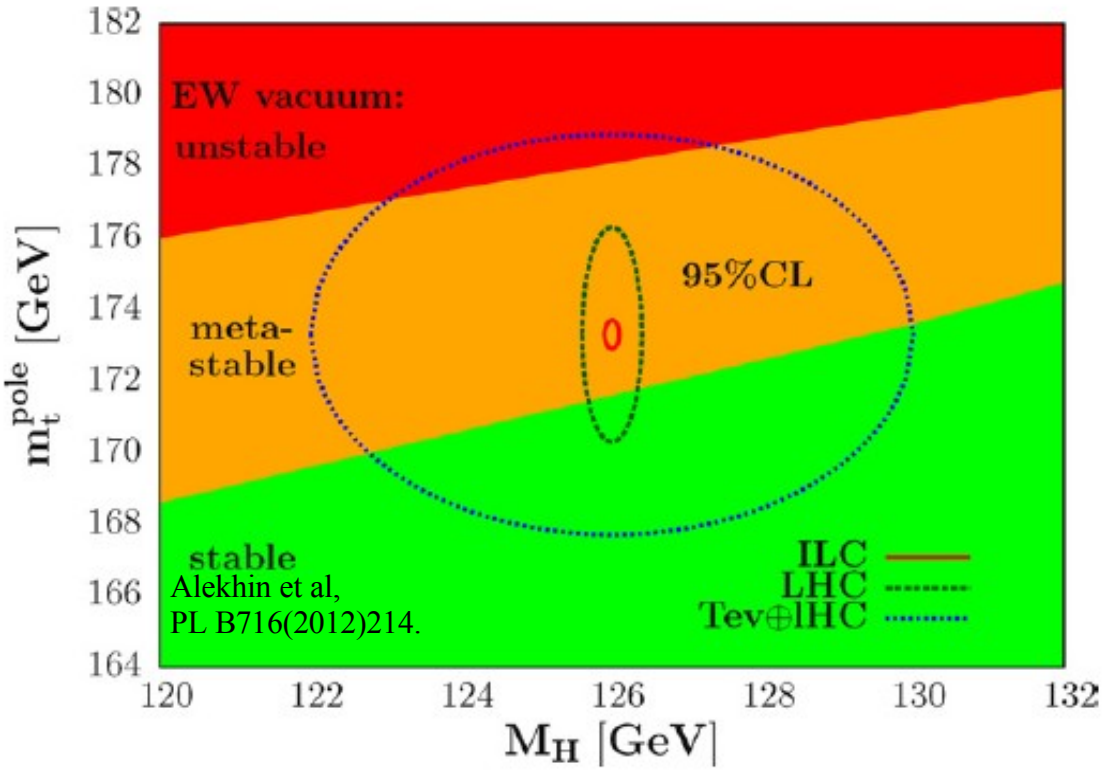
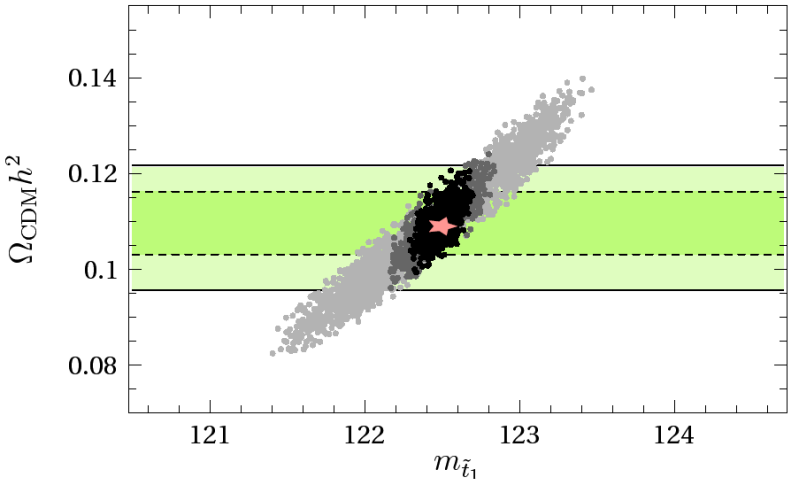


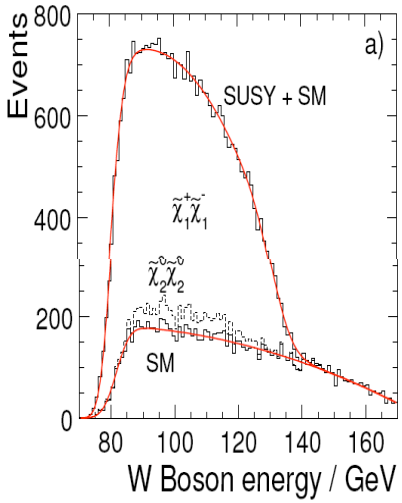
Alekhin et al,
PL B716(2012)214.

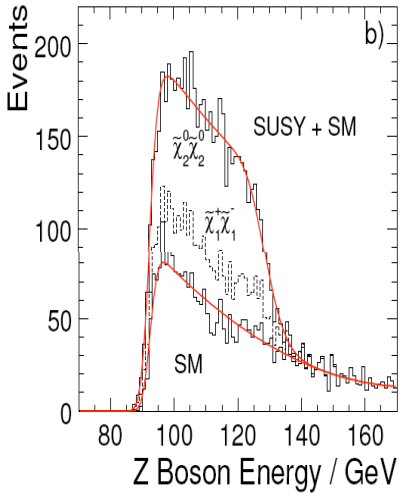
Physics beyond the Higgs

A linear collider is

- A top factory (if E >threshold)
- A Standard Model physics center
- A discovery machine

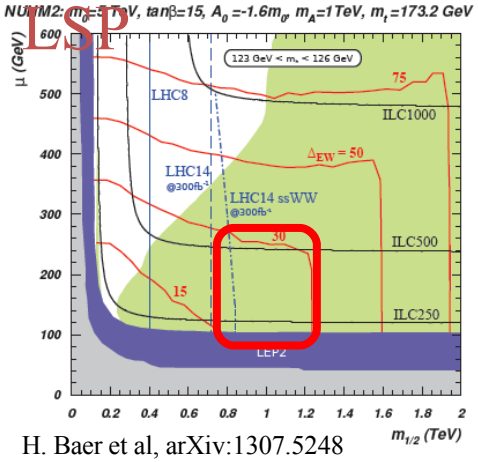






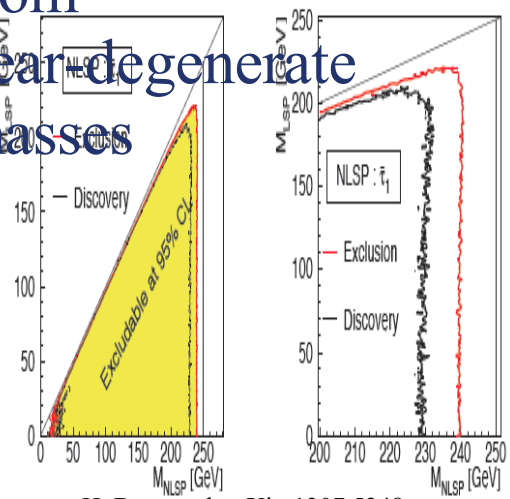
Where ILC Would Help

Higgsino-like LSP



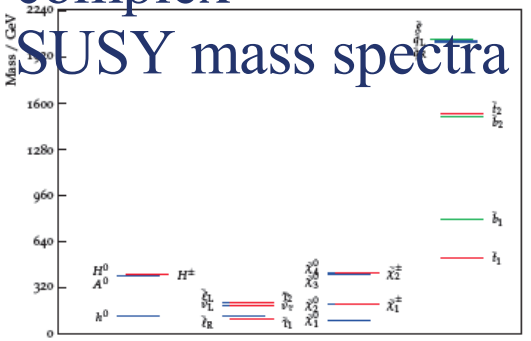
H. Baer et al, arXiv:1307.5248
and arXiv:1306.3148

Closing loopholes from near-degenerate masses



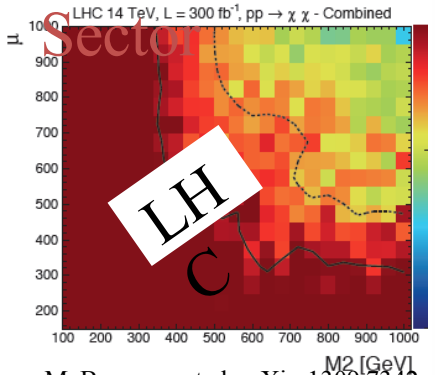
H. Baer et al, arXiv:1307.5248

Understanding complex SUSY mass spectra

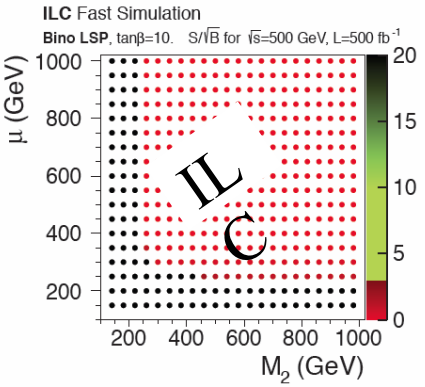


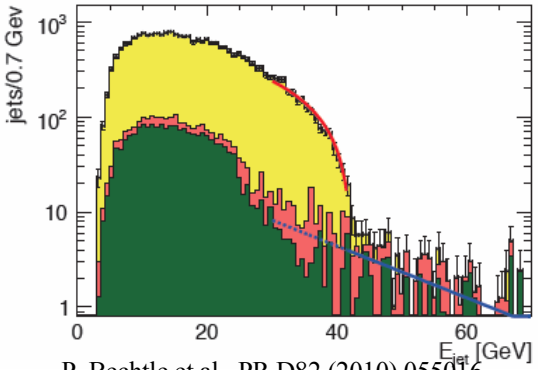
H. Baer, J. List, arXiv:1307.0782

Elektroweakino Sector



M. Berggren et al, arXiv:1309.7342





P. Bechtle et al., PR D82 (2010) 055016.

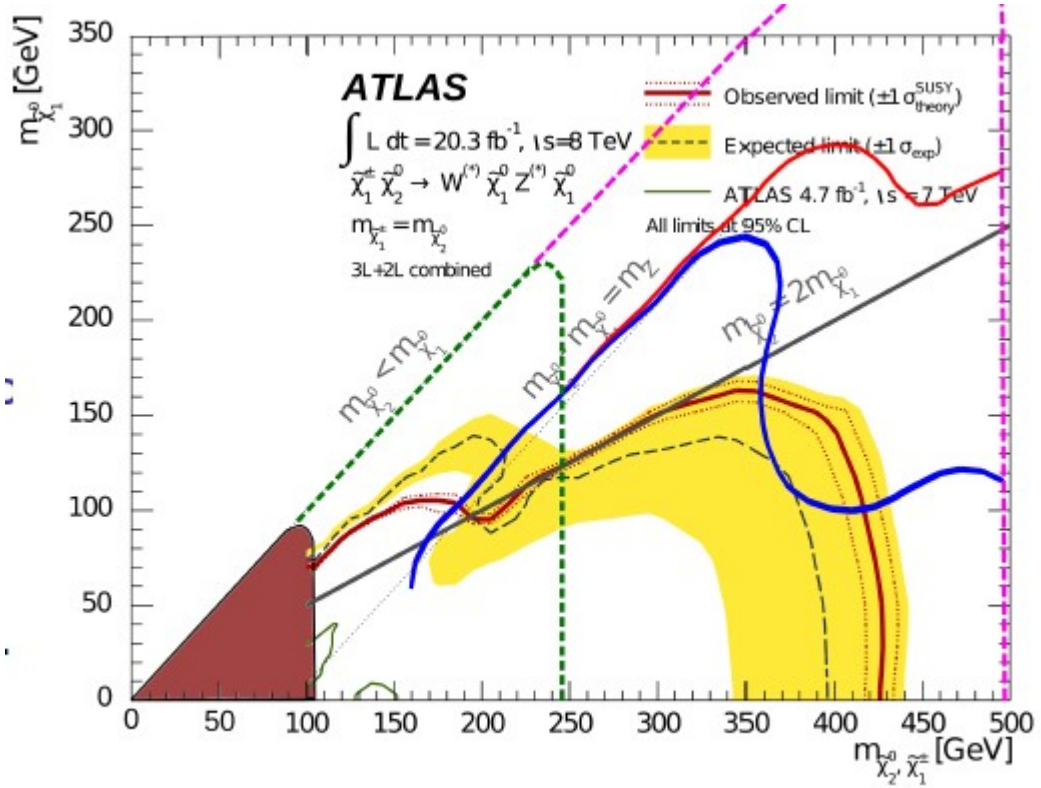
The Role of the ILC

LHC including HL-LHC

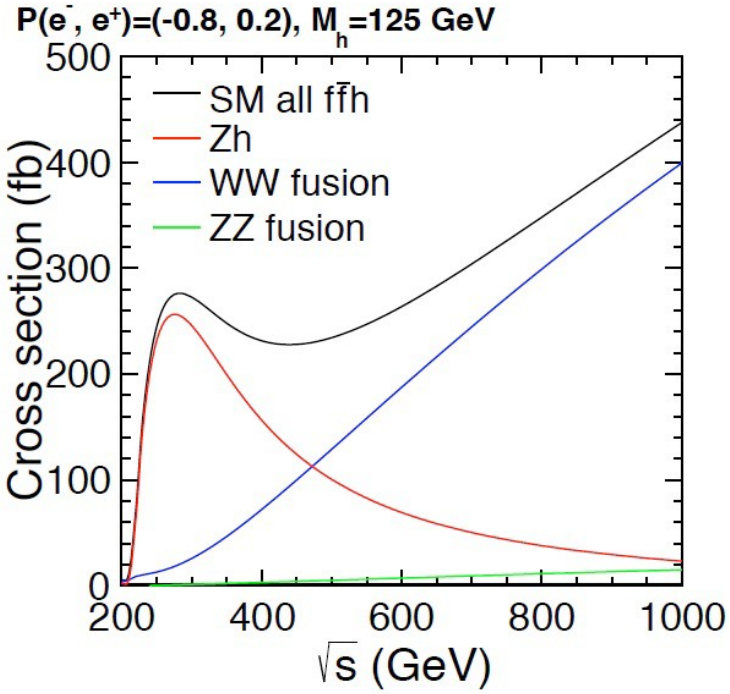
LEP

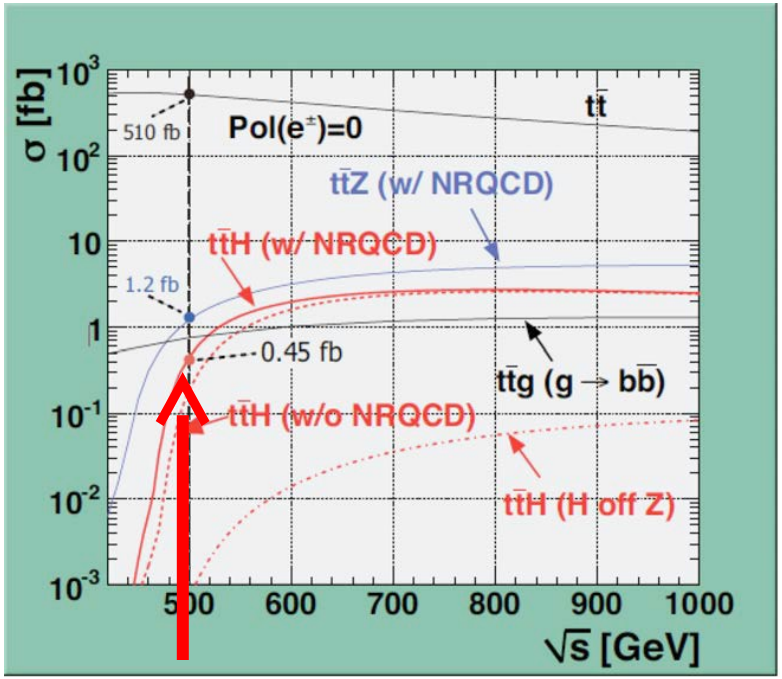
Plus ILC 500

Plus ILC 1000



How to define the optimal program

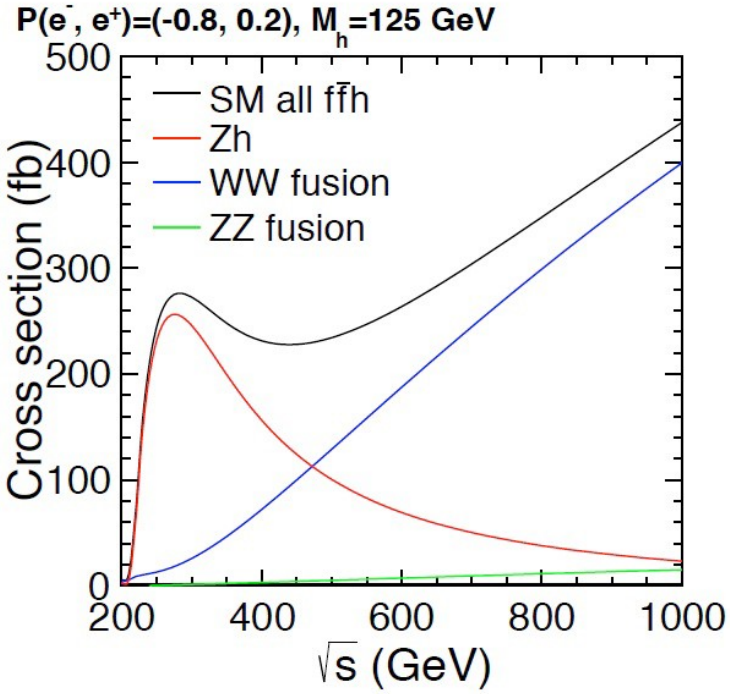


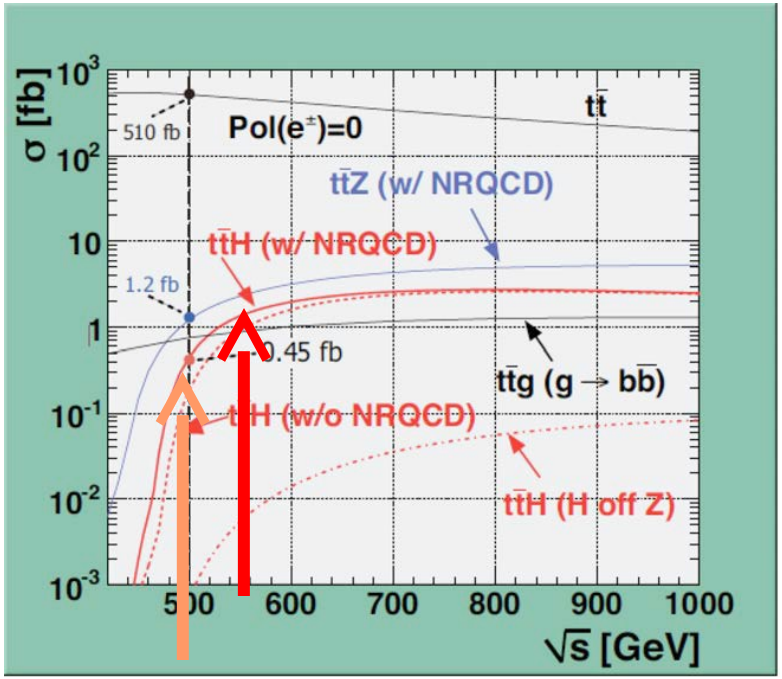


Higgs program:
250 GeV for ZH
350 (500) GeV for HWW

Top physics:
500 vs 550 GeV make a difference

How to define the optimal program



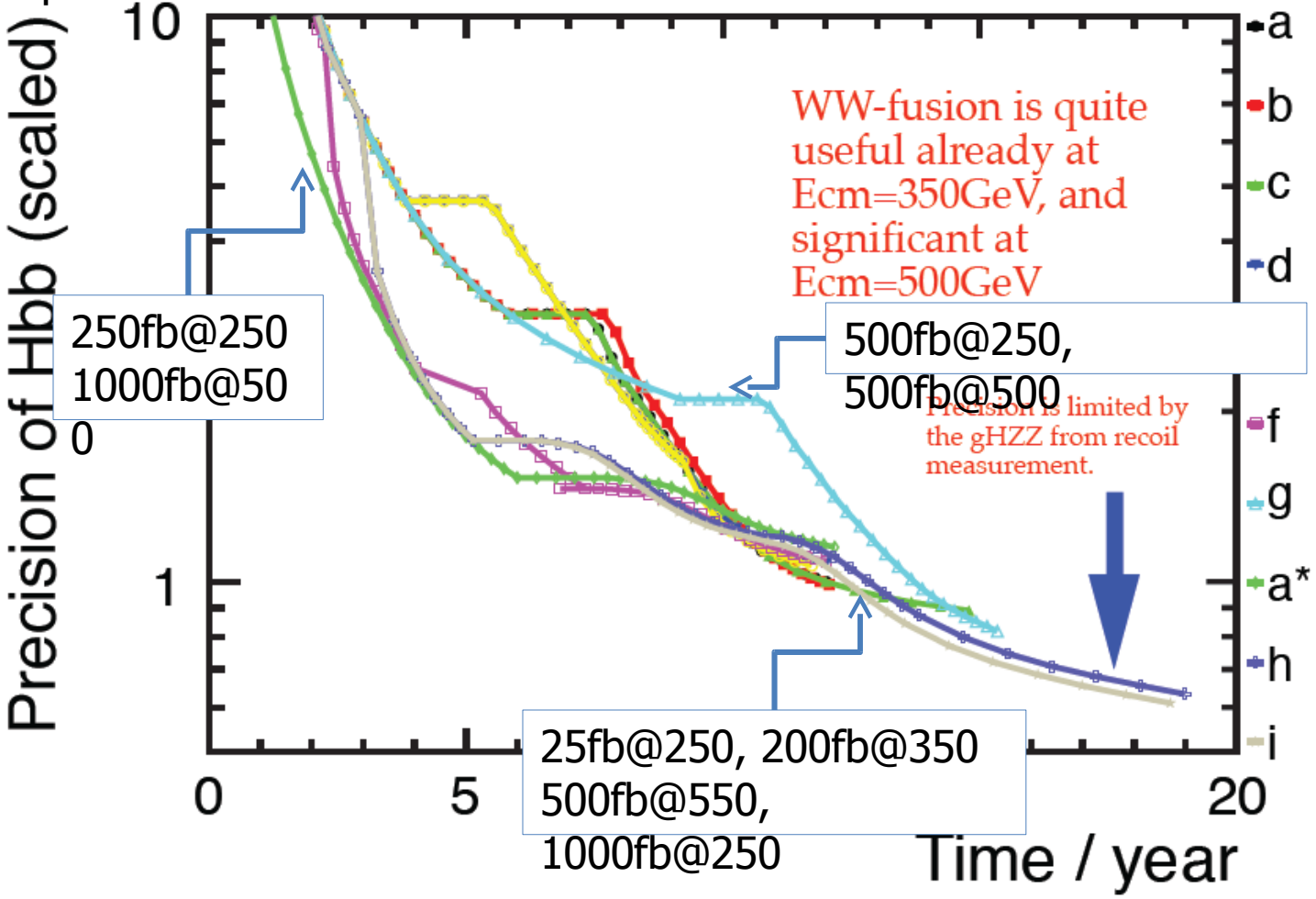


Higgs program:
250 GeV for ZH
350 (500) GeV for HWW

Top physics:
500 vs 550 GeV make a difference

Running scenarios

ILC baseline: 500 GeV machine, standard parameters



Concrete Proposals

Circular Colliders@CERN

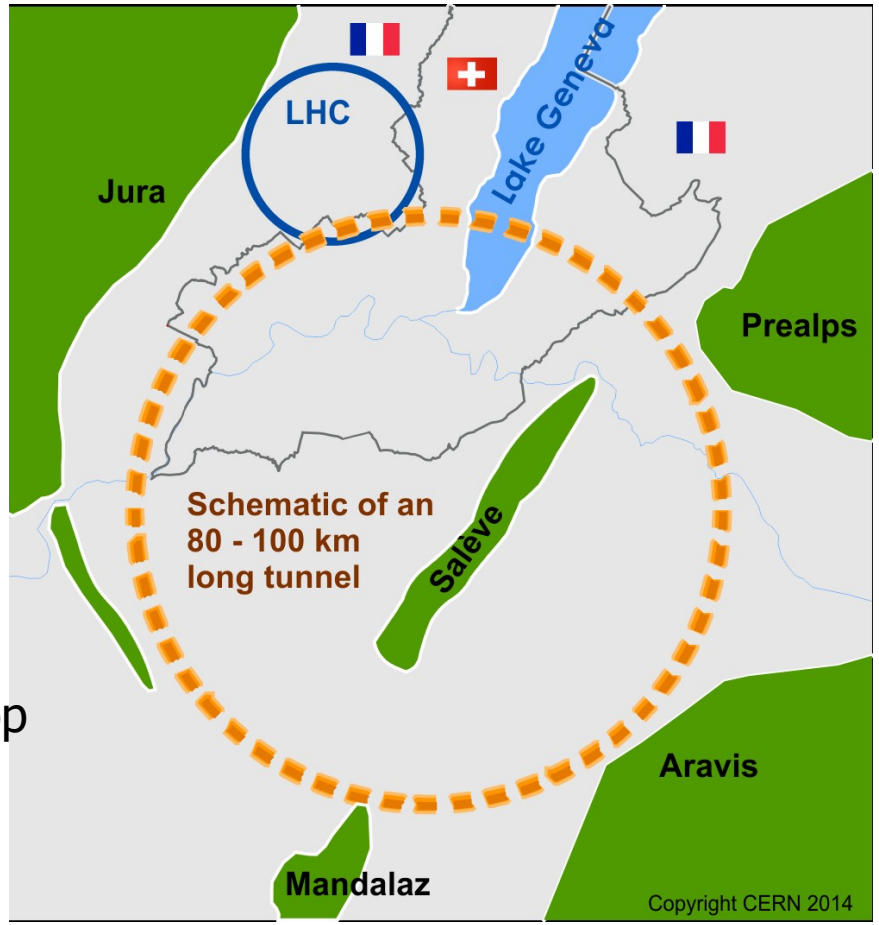
FCC: Future Circular Collider
Main parameters under study:

- ***pp*-collider (*FCC-hh*)**
defining infrastructure requirements
- ***e+e*-collider (*FCC-ee*)**
as potential intermediate step
- ***p-e* (*FCC-he*) option**
- **80–100 km infrastructure**
in Geneva area

Energy for e+e-: higgs factory, maybe top

A similar proposal is under discussion in China (250 GeV Higgs factory)

Goal: CDR in 2018, timescale: 2030++



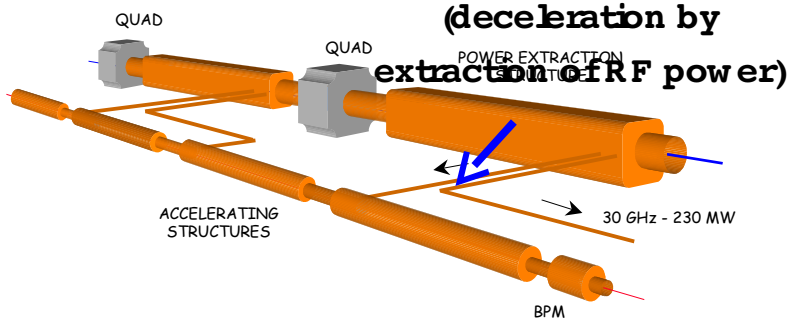
CLIC

Two Beam Scheme

Drive Beam supplies RF power

- 12 GHz bunch structure
- low energy (2.4 GeV - 240 MeV)
- high current (100A)

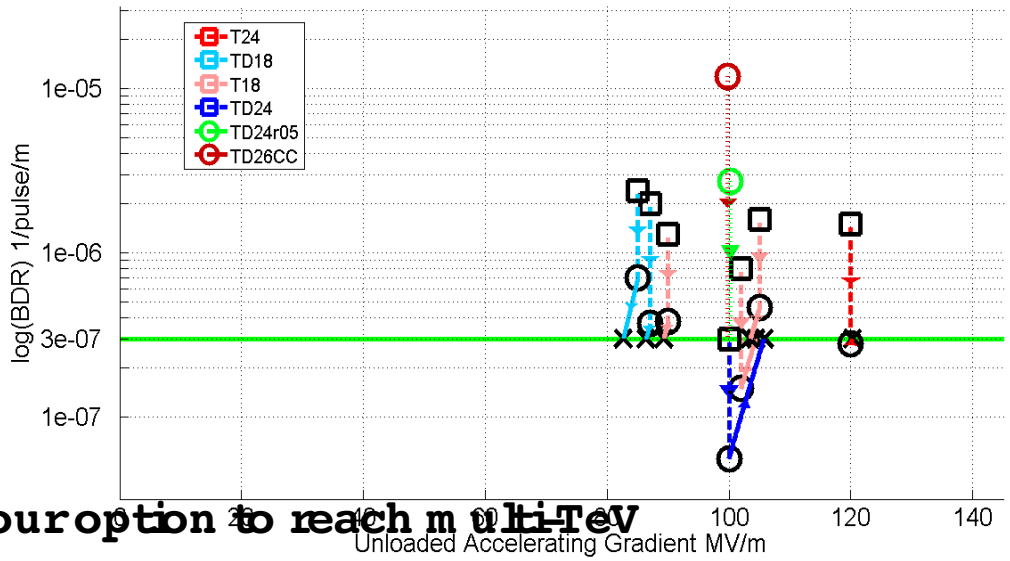
Drive beam – 100 A from 2.4 GeV -> 240 MeV (deceleration by extraction of RF power)



Main beam for physics

- high energy (9 GeV – 1.5 TeV)
- current 1.2 A

Up to 3 TeV E(cms) anticipated



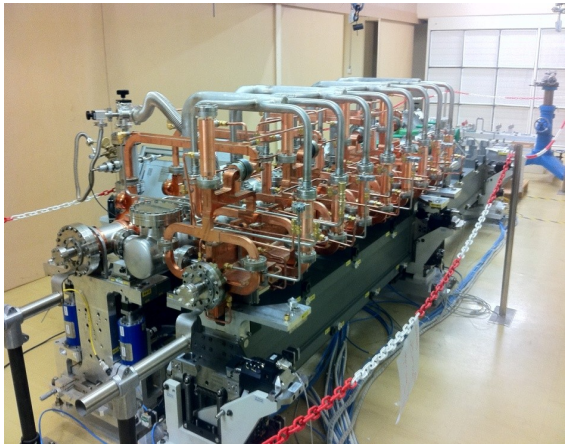
Technology is not fully proven

Intense R&D effort at CERN

CLIC: our option to reach multi-TeV energies in lepton collisions in the future.

Timescale 2030+

CLIC Performance



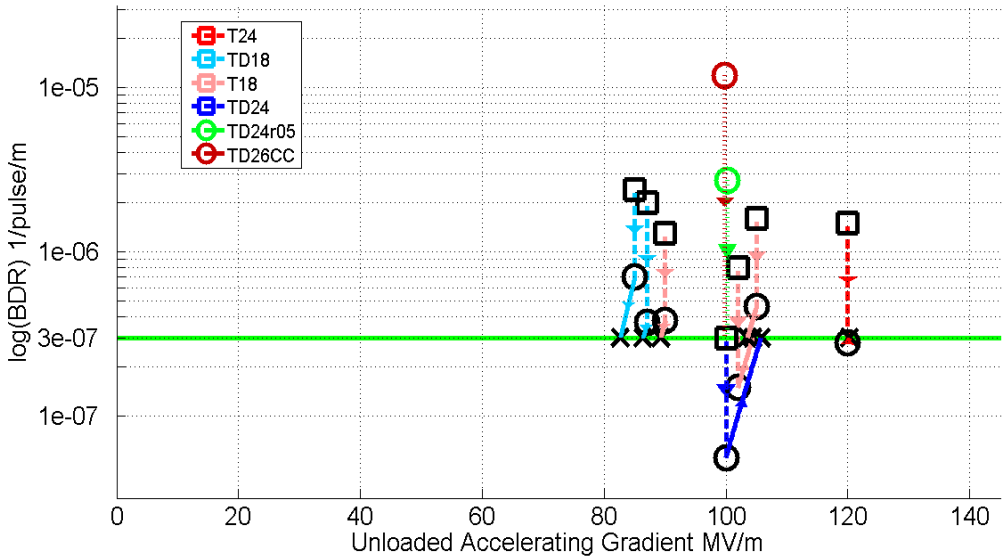
Significant progress over the past few years:

- Optimization of RF system and gradient
- Re-baselined the collider for staged operation
- Optimized cost-performance

Results very good – but:

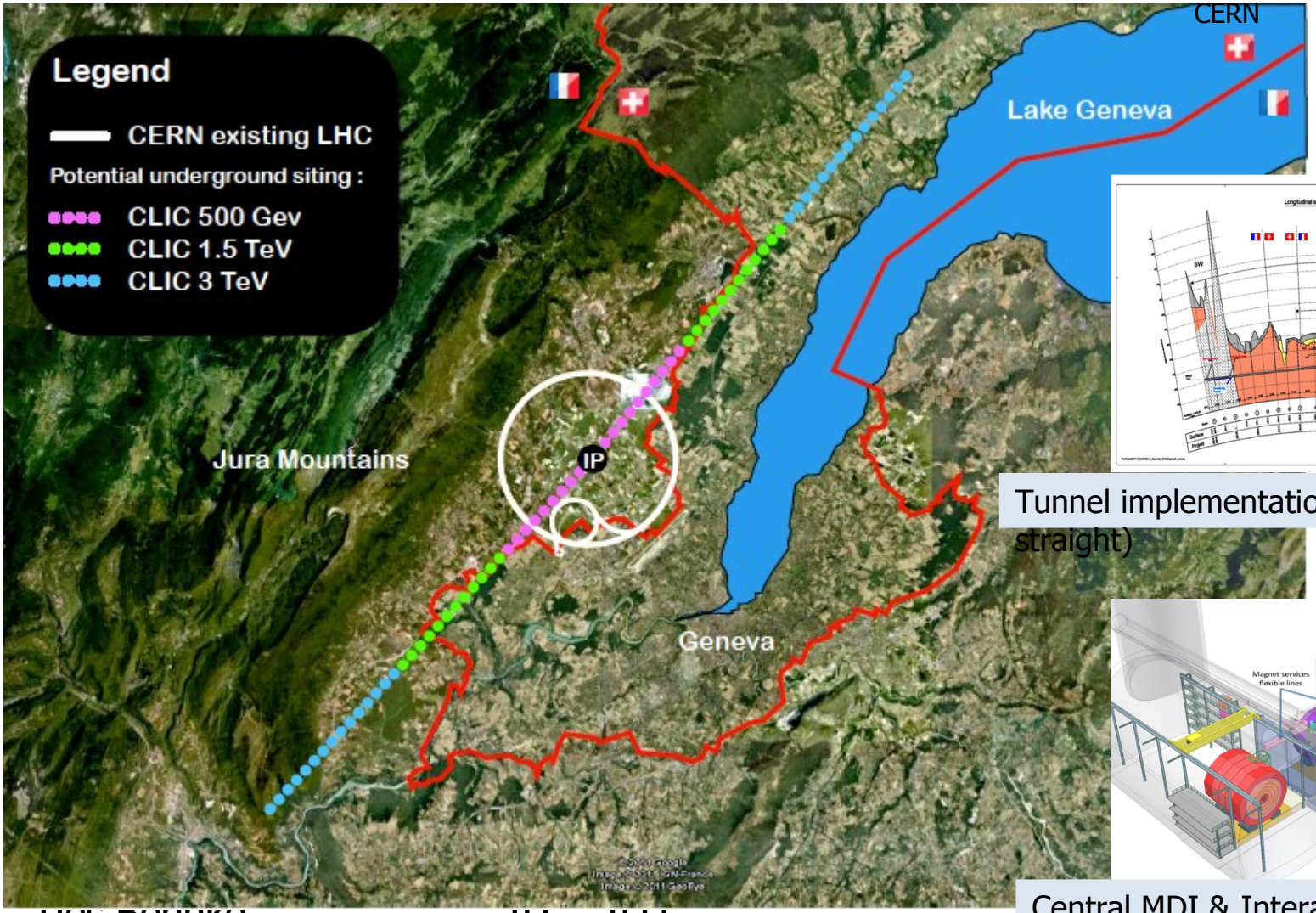
- numbers limited, industrial productions also limited
- basic understanding of BD mechanics improving
- condition time/acceptance tests need more work
- use for other applications (e.g. FELs) needs verification

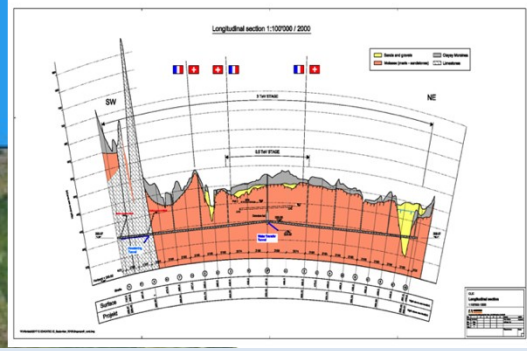
In all cases test-capacity is crucial



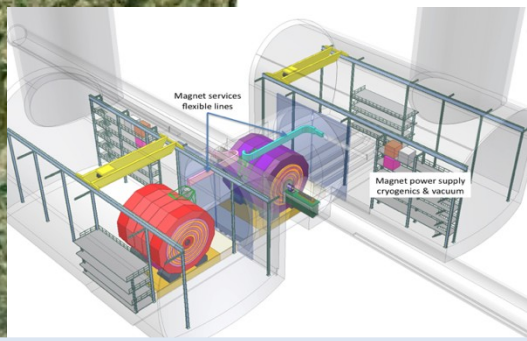
CLIC@CERN

Slide by Steinar Stapnes, CERN



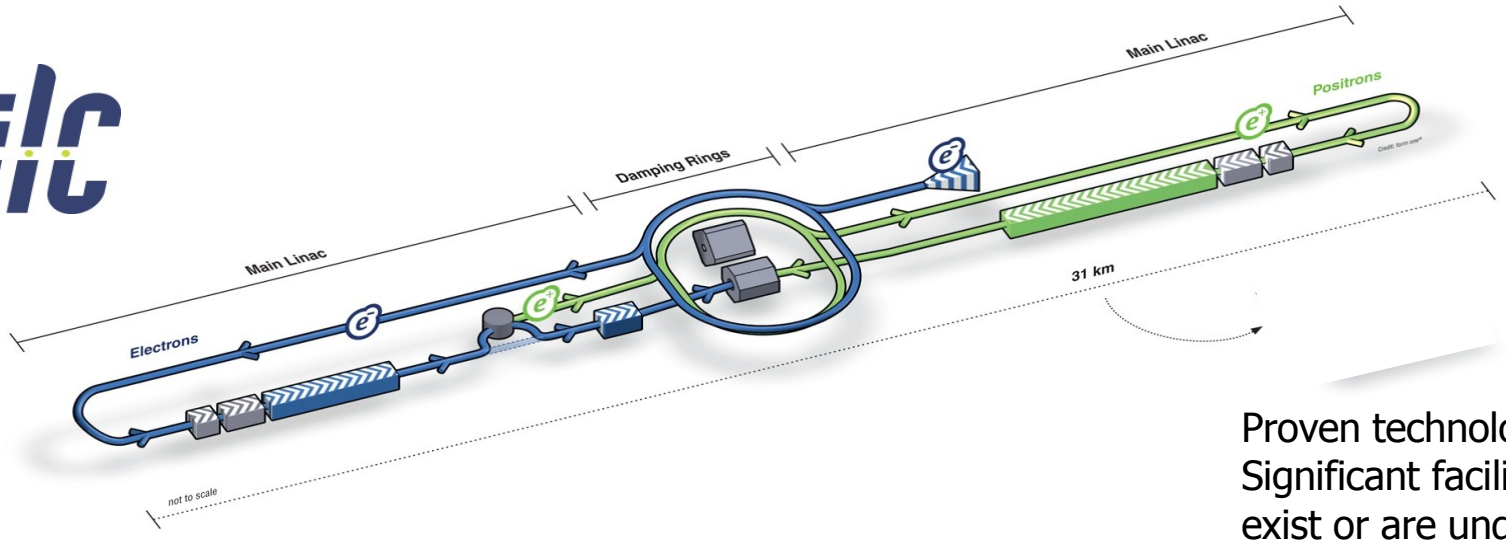


Tunnel implementations (laser straight)



Central MDI & Interaction Region

The International Linear Collider

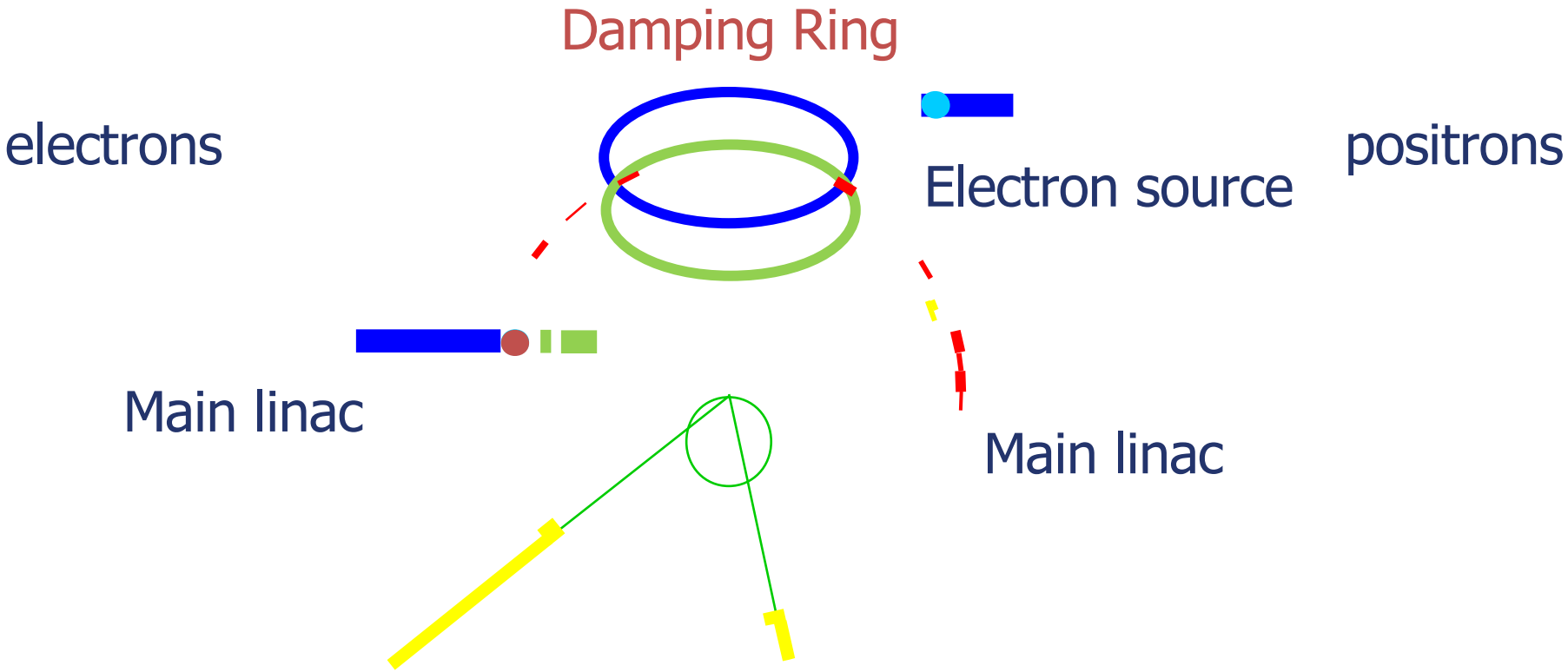


Proven technology
Significant facilities exist or are under construction (XFEL)

The international Linear Collider:

- Electron Positron Collisions
- Superconducting acceleration technology
- High Luminosity at E=500GeV to 1 TeV or lower energies
- About 31km site length

How Does it Work?



Animation by T. Takahashi (Hiroshima)

Why Superconducting?

- Linear accelerator: Accelerate electrons in a long string of RF cavities
- Gradient: 31.5MV/m
  ☐ need 15.8km for 500GeV!

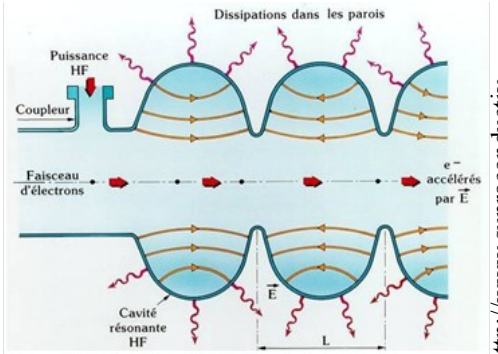
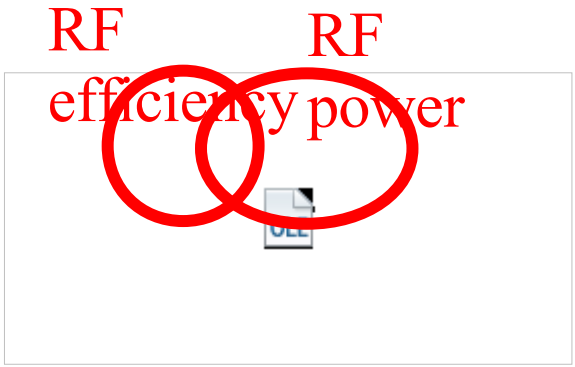


Figure 1 Schéma de la distribution du champ électrique dans une cavité résonnante

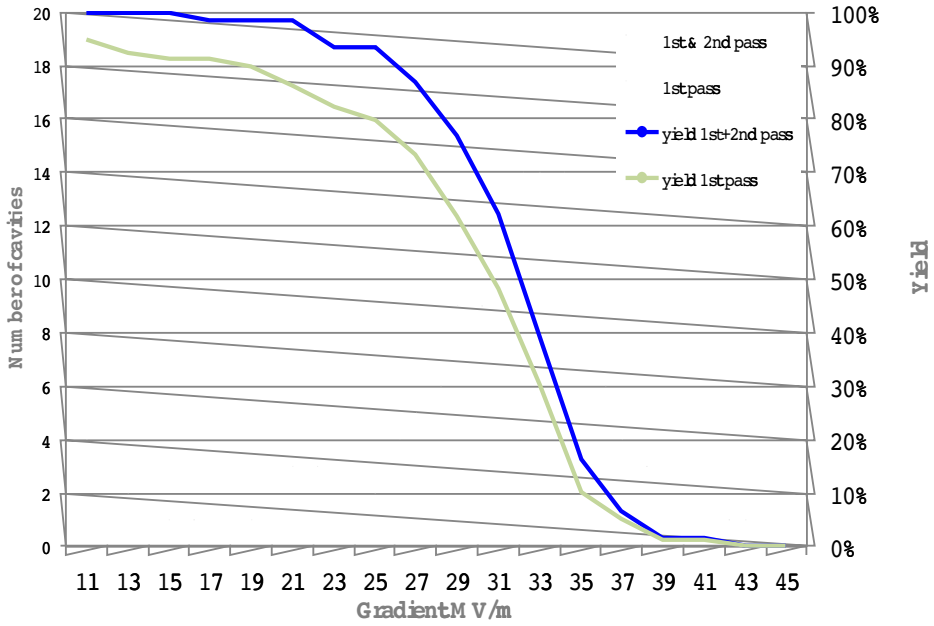
http://www.supraconductivite.fr/media/images/Applications/image037.png

- For given total power (electricity bill!), luminosity proportional to efficiency
- ILC: total site power ~160MW @ 500GeV



- Superconducting cavities maximise RF-to-beam efficiency

ILC Performance



ILC baseline design

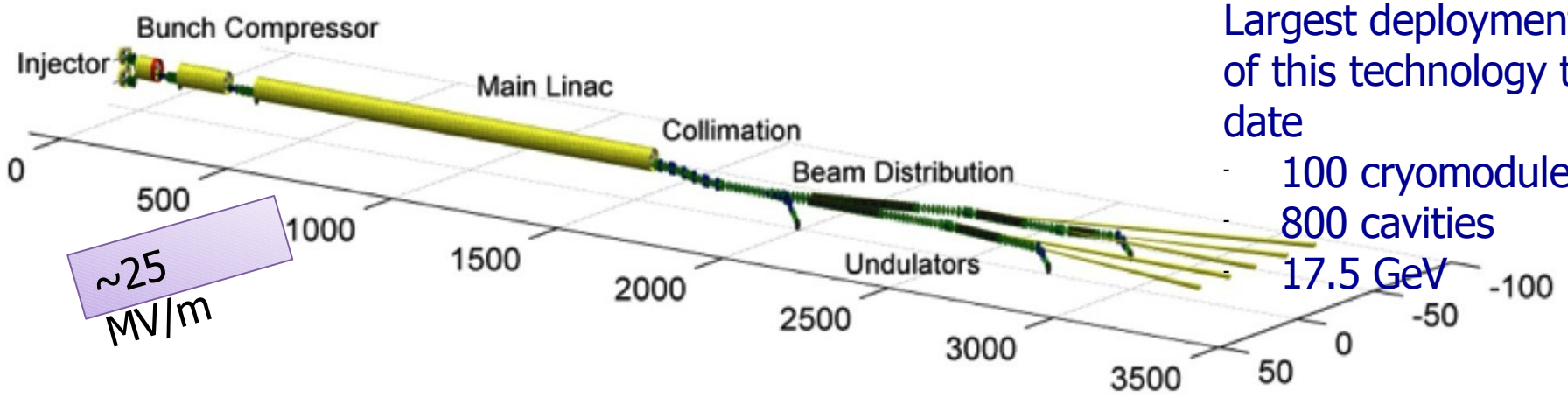
- Superconducting cavities
- 31.5 MV/m gradient
- Well developed, tested design of
  cryo modules, internationally accessible.

XFEL production line: maximum gradient
reached

SCRF Cavities: Almost a Stock Item

Graphic: Benno List, DESY

European XFEL @ DESY



Largest deployment of this technology to date

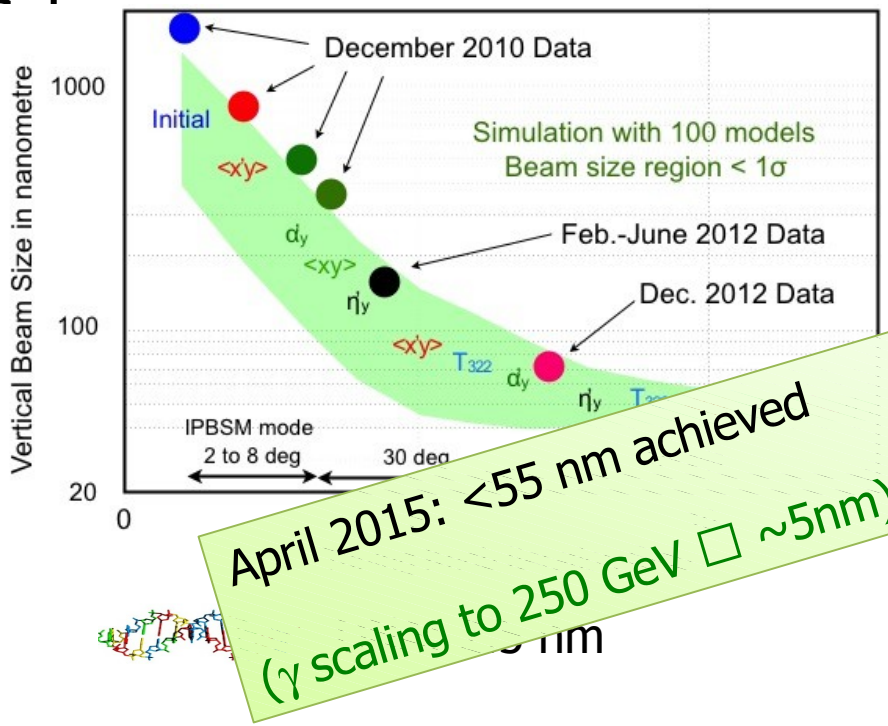
- 100 cryomodules
- 800 cavities
- 17.5 GeV

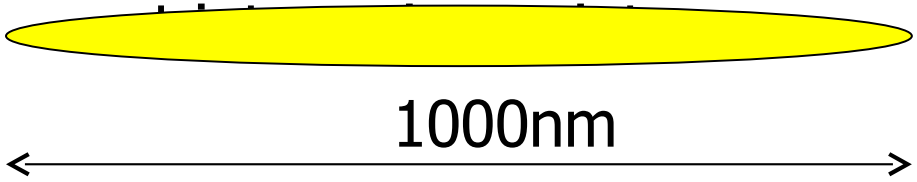
Institute	Component Task
CEA Saclay / IRFU, France	Cavity string and module assembly; cold beam position monitors
CNRS / LAL Orsay, France	RF main input coupler incl. RF conditioning
DESY, Germany	Cavities & cryostats; contributions to string & module assembly; coupler interlock; frequency tuner; cold-vacuum system; integration of superconducting magnets; cold beam-position monitors
INFN Milano, Italy	Cavities & cryostats
Soltan Inst., Poland	Higher-order-mode coupler & absorber
CIEMAT, Spain	Superconducting magnets
IFJ PAN Cracow, Poland	RF cavity and cryomodule testing
BINP, Russia	Cold vacuum components

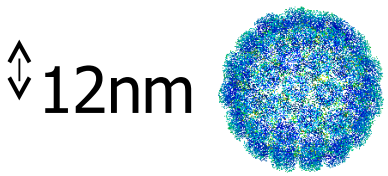
The ultimate '**integrated system test**' for ILC.

How to get the Luminosity

- Design: L=1.74 □ 1034 cm-2s-1
  requires:
- Very small beams at interactio
  RMS size is 500 nm x 6 nm!
- This needs:
  - Beams with extremely low emittance
  - Extremely strong focusing







Virus: 20nm

ILC Published Parameters

Centre-of-mass dependent:

Centre-of-mass energy	**GeV**	**200**	**230**	**250**	**350**	**500**
Electron RMS energy spread	%	0.21	0.19	0.19	0.16	0.12
Positron RMS energy spread	%	0.19	0.16	0.15	0.10	0.07
IP horizontal beta function	mm	16	16	12	15	11
IP vertical beta function	mm	0.48	0.48	0.48	0.48	0.48
IP RMS horizontal beam size	nm	904	843	700	662	474
IP RMS veritcal beam size	nm	9.3	8.6	8.3	7.0	5.9
Vertical disruption parameter		20.4	20.4	23.5	21.1	24.6
Enhancement factor		1.83	1.83	1.91	1.84	1.95
Geometric luminosity	×1034 cm-2s-1	0.25	0.29	0.36	0.45	0.75
Luminosity	**×1034 cm-2s-1**	**0.50**	**0.59**	**0.75**	**0.93**	**1.8**
% luminosity in top 1% ΔE/E		92%	90%	84%	79%	63%
Average energy loss		1%	1%	1%	2%	4%
Pairs / BX	×103	41	50	70	89	139
Total pair energy / BX	TeV	24	34	51	108	344

http

ILC Published Parameters

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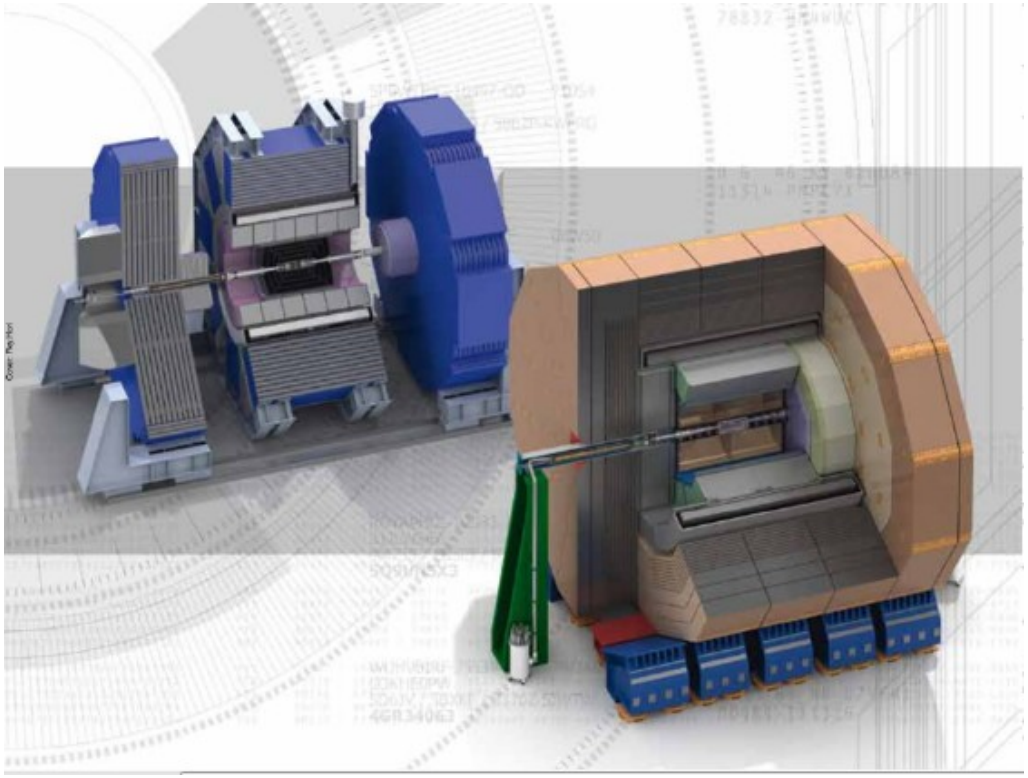
Vertical disruption parameter		20.4	20.4	23.5	21.1	24.6
Enhancement factor		1.83	1.83	1.91	1.84	1.95
Geometric luminosity	×1034 cm-2s-1	0.25	0.29	0.36	0.45	0.75
Luminosity Upgrade	**×1034 cm-2s-1**	**1.00**	**1.18**	**1.50**	**1.86**	**3.6**
% luminosity in top 1% ΔE/E		92%	90%	84%	79%	63%
Average energy loss		1%	1%	1%	2%	4%
Pairs / BX	×103	41	50	70	89	139
Total pair energy / BX	TeV	24	34	51	108	344

http



Realising the ilc

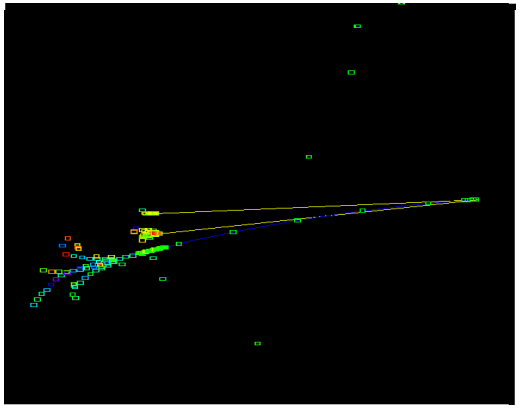
The ILD detector

Siting the ILC in Japan

Design Philosophy

Particle flow as main reconstruction technique

Imaging Calorimeters (CALICE)
Extreme granularity wins over energy resolution,
in particular in the HCAL



High power tracking

High efficiency, robust tracking in dense environments
High precision vertexing for heavy flavour physics

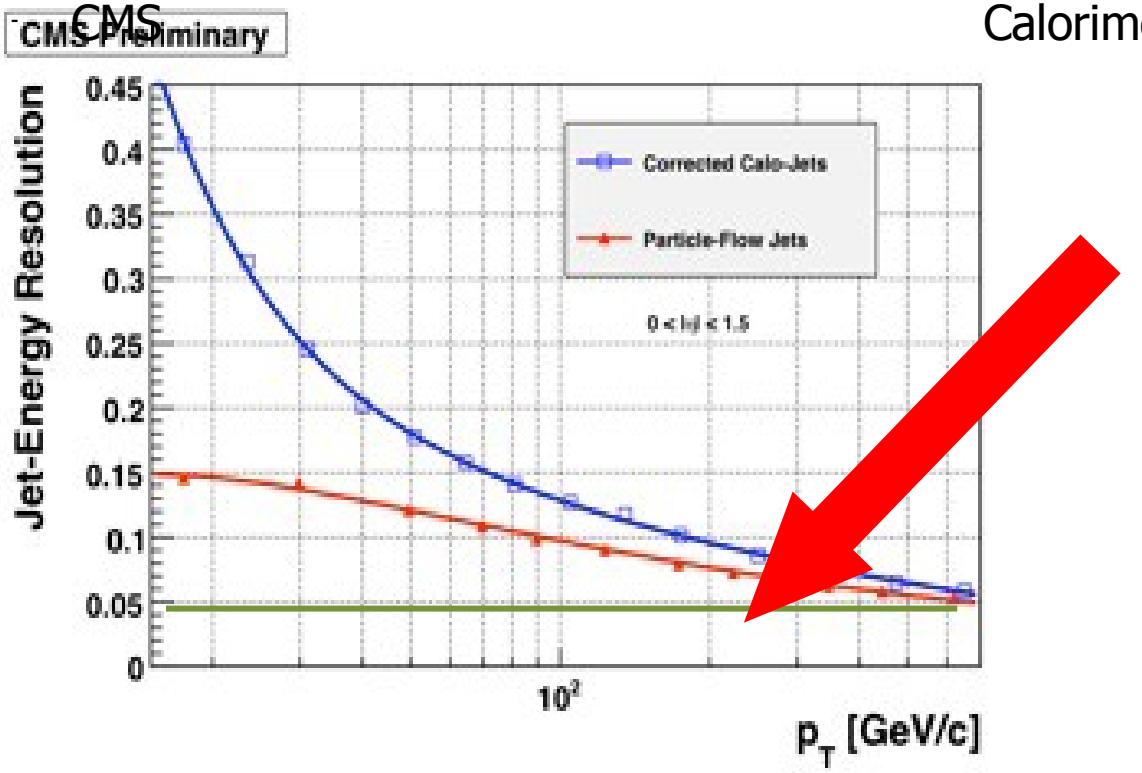
The Particle Flow Paradigm

Particle flow is not new:

- LEP detectors (Aleph in particular)
- CDF
- CMS

Energy resolution is not the most important point

Pattern recognition in the Calorimeter

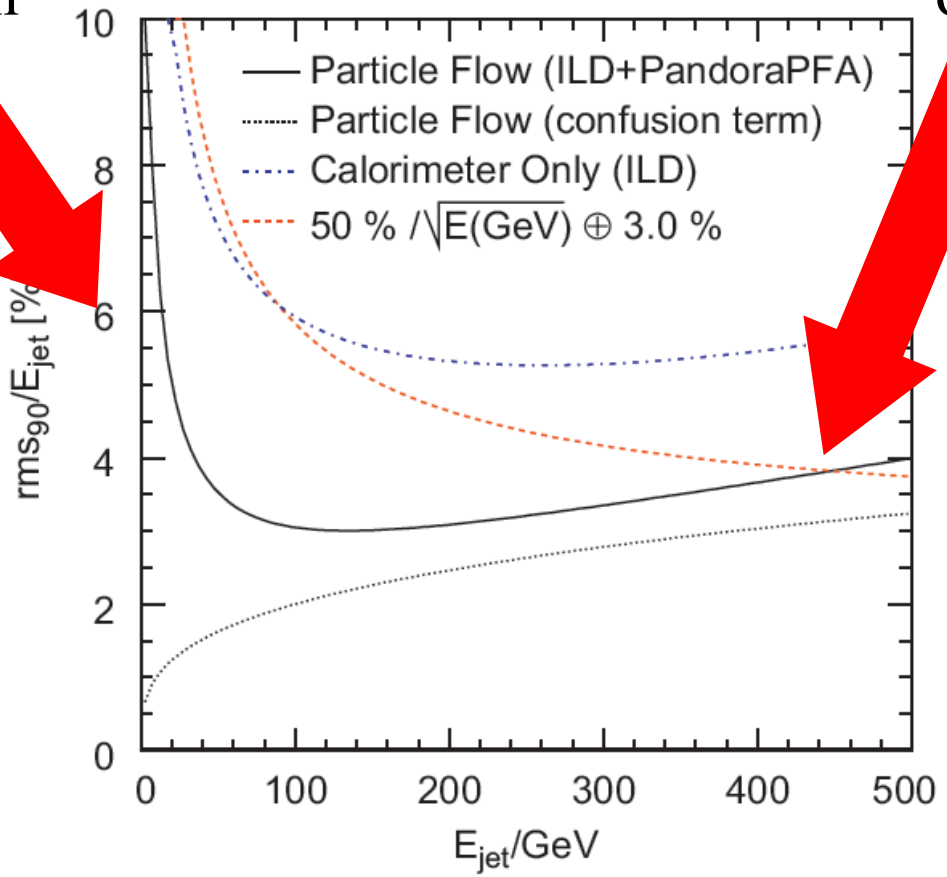


Linear Collider Goal:
Significantly better than
CMS performance

Particle Flow

Energy resolution

Confusion

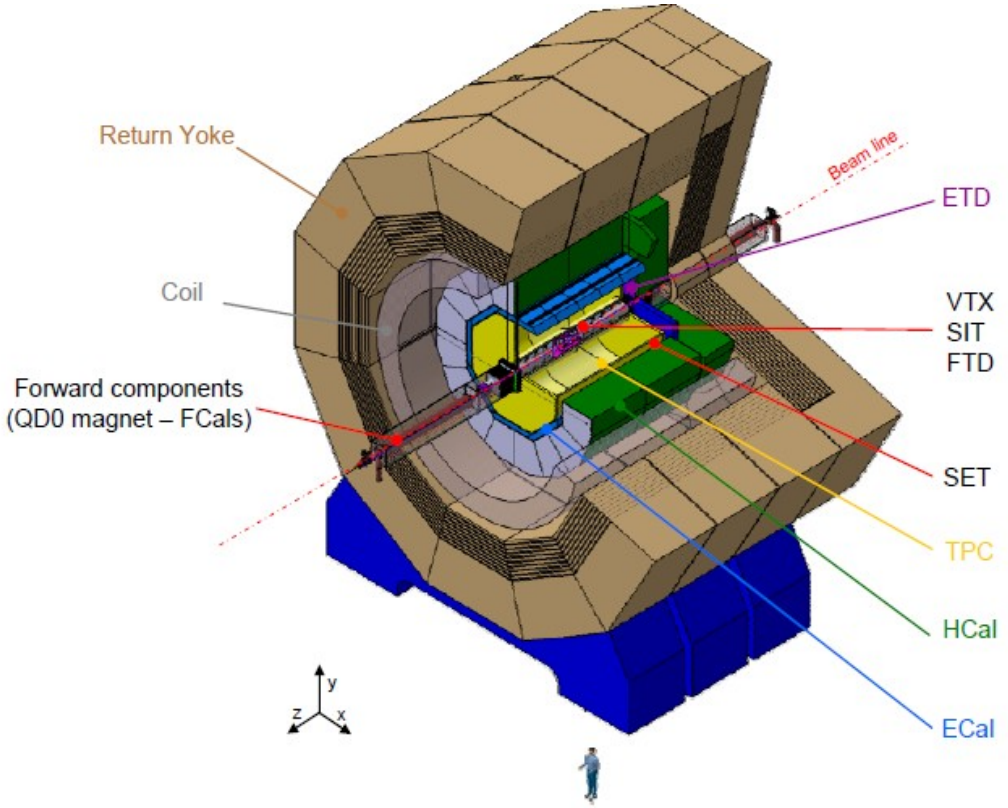


Particle flow is better than pure calorimetry

At high energies the

advantage is lost.

Detector Layout



Typical multi-purpose detector

precision tracking
precision calorimetry
precision muon system
hermetic

ILD is one of two well developed (and complementary) concepts

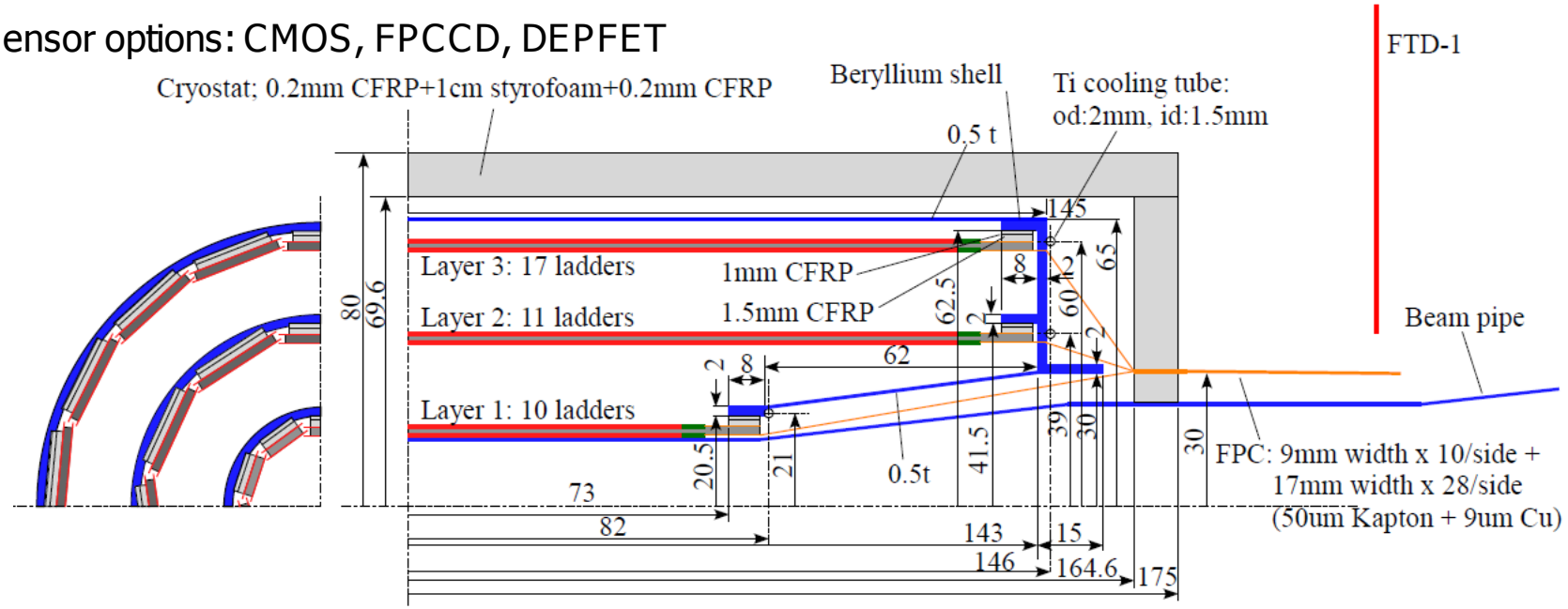
Vertex Detectors

- Excellent spatial resolution
- Very low material budget

	ILC	*Belle-II*
occupancy	0.13 hits/μm^2/s	0.4 hits/μm^2/s
Radiation	< 100 krad/year, 10^{11} 1 MeV n_{eq}/year	> 1Mrad/year, 2×10^{12} 1 MeV n_{eq}/year
Duty cycle	1/200	1
Frame time	25-100 µs (10 ns @ CLIC)	20 µs
Momentum range	All momenta	Low momentum (< 1 GeV)
Acceptance	6°-174°	17°-150°
Resolution	Excellent 3-5 µm (pixel size = 20 x 20 μm^2)	Moderate (pixel size = 50 x 75 μm^2)
Material budget	0.15 % X_0/layer	0.21 % X_0/layer

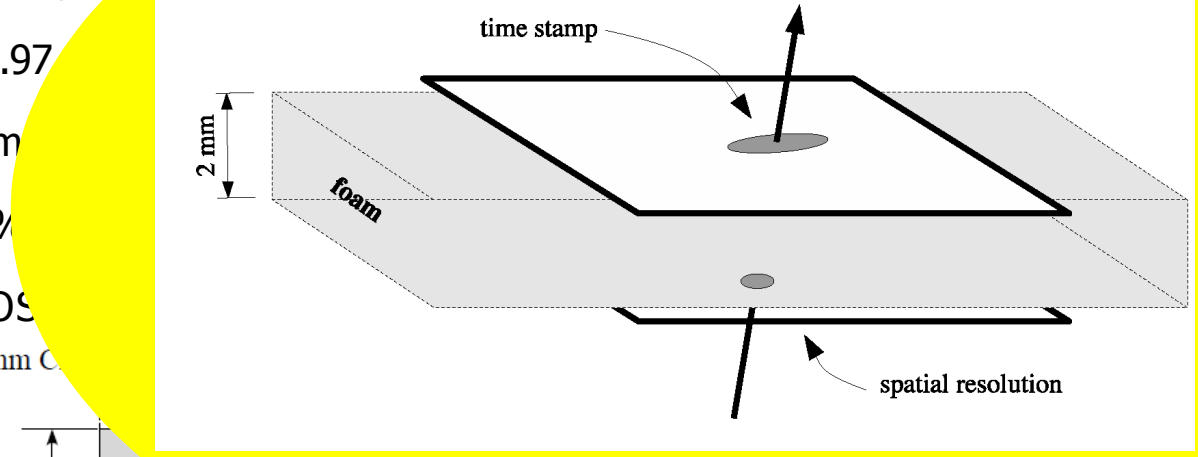
Vertex detector

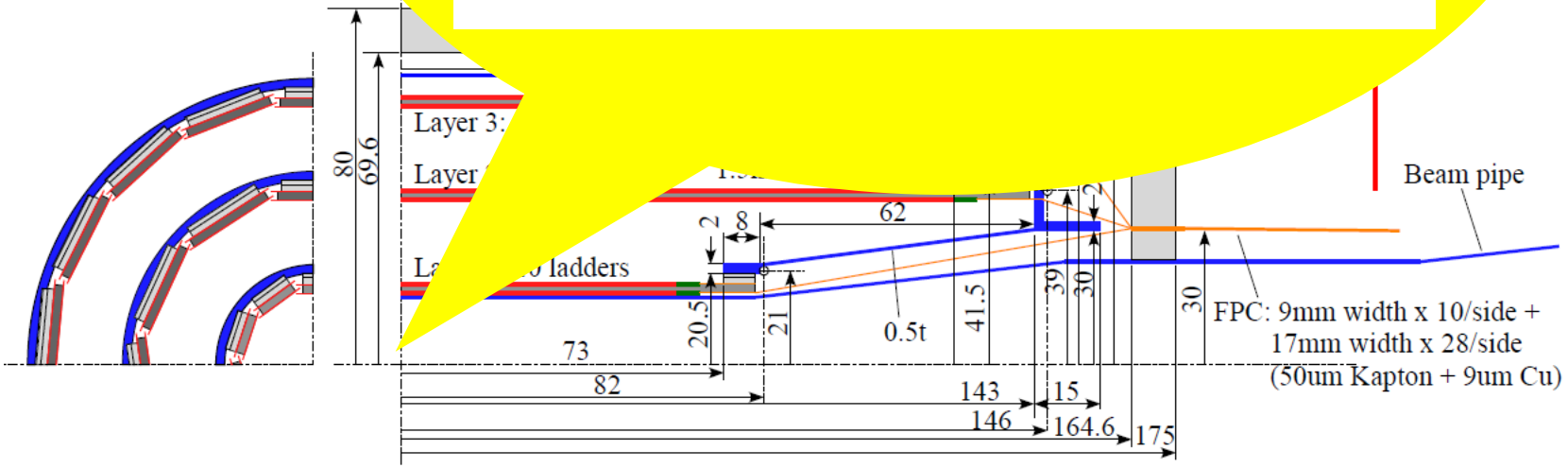
- Excellent impact parameter resolution better than 5⊕10/pbsin3/2q is required for efficient flavor tagging
- 3 layers of double ladders (ca 100 um apart) (6 pixel layers)
  - Effect on pair-background rejection is expected, but not demonstrated yet
- Barrel only: |cosq|<0.97 for inner layer and |cosq|<0.9 for outer layer
- Point resolution <3um for innermost layer
- Material budget: 0.3%X0/ladder=0.15%X0/layer
- Sensor options: CMOS, FPCCD, DEPFET



Vertex detector

- Excellent impact parameter resolution better than 5⊕10/pbsin3/2q is required for efficient flavor tagging
- 3 layers of double ladders (ca 100
  - Effect on pair-backgrou
- Barrel only: |cosq|<0.97
- Point resolution <3um
- Material budget: 0.3%
- Sensor options: CMOS



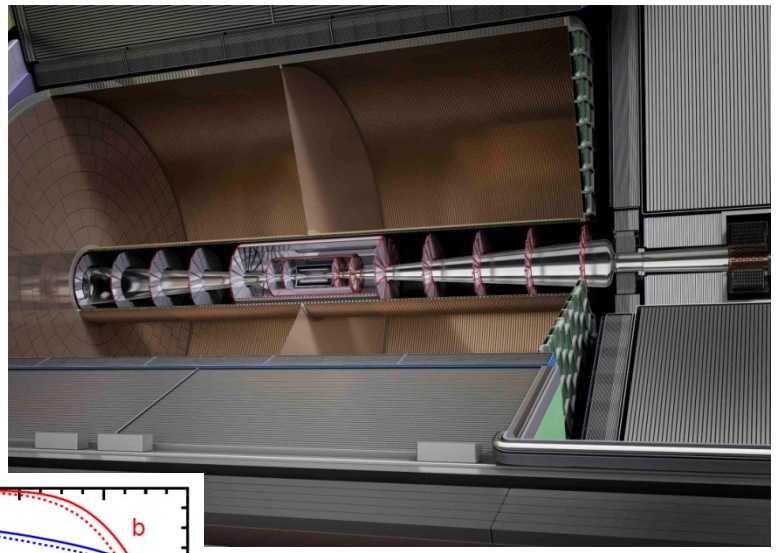


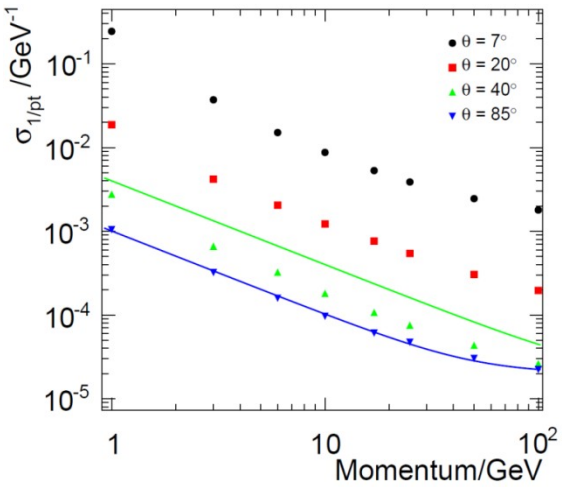
Tracking Detector

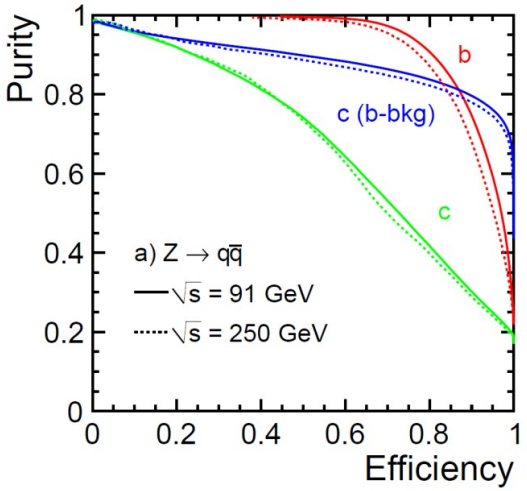
Pixel Vertex at small radii

Intermediate Silicon tracking

Large Volume TPC







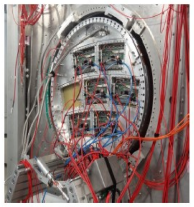
Intense R&D effort

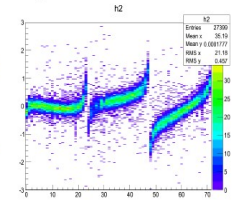
- Proof of concept done
- Performance reached
- Cost performance optimization ongoing

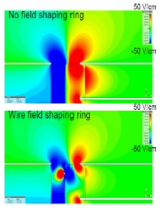
TPC/ Silicon Tracking

- Time Projection Chamber: The central tracker of ILD
- Tracks can be measured with many (~200/track) 3-dimensional r-f-z space points
- srf<100um is expected
- dE/dx information for particle identification
- Two main options for gas amplification: GEM or Micromegas
- Readout pad size ~ 1x6mm2 □106 pads/side
- Pixel readout R&D as a future alternative
- Material budget: 5%X0 in barrel region and <25%X0 in endplate region
- Cooling by 2-phase CO2
- Backed up by extensive Silicon tracking in front and behind TPC

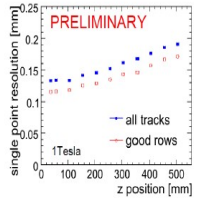
Multi-module setups with highly integrated electronics are tested in the LP:
For example the 6-module setup with MM+resistive layer modules in 7/2012.

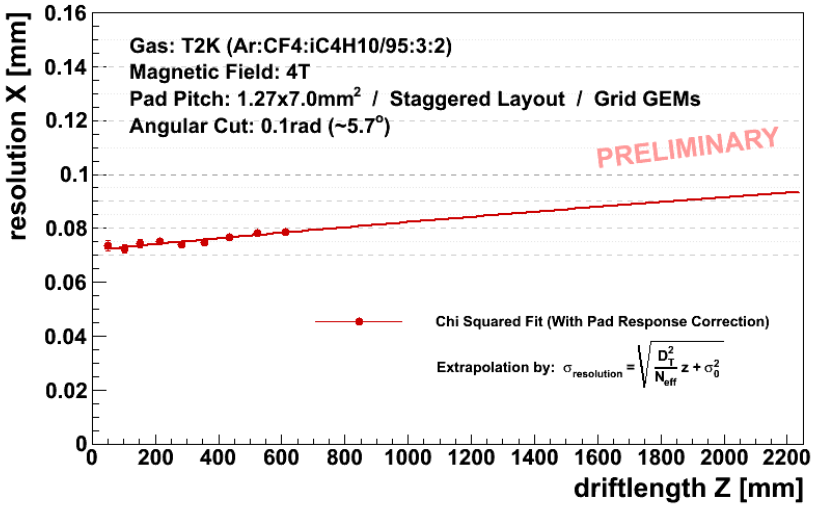






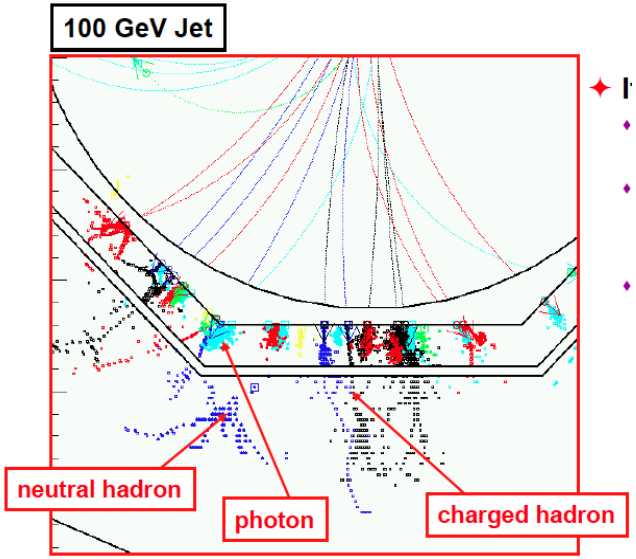
Field distortions at the border of the modules are seen with all gas amplification technologies (GEMs, MM, InGrids) and solutions are being investigated.





Calorimetry

Calorimetry is at the heart of any particle flow



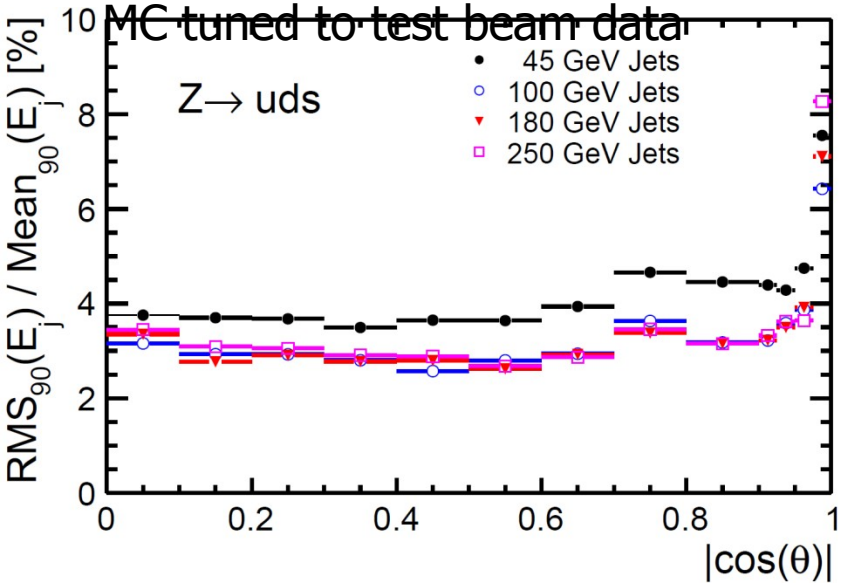
M. Thomson, Calor 2010

Highly granular, thick, calorimeters

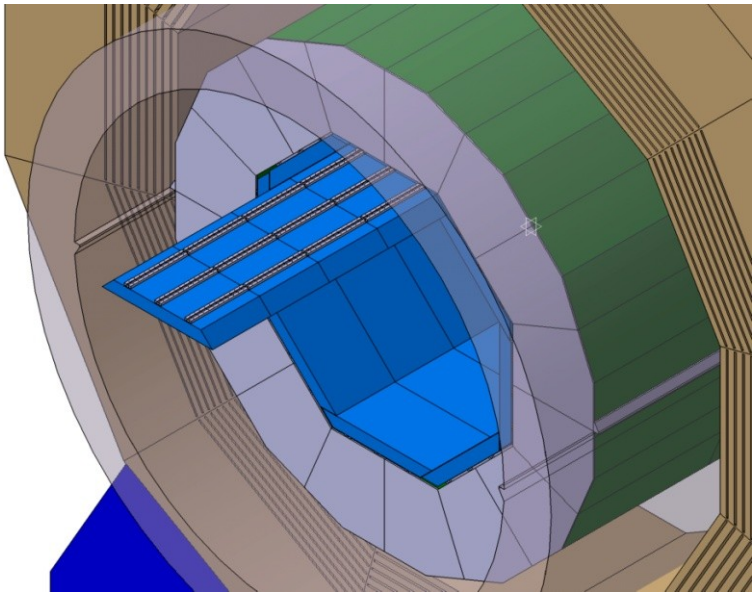
Several technologies studied

- Si-W
- Scintillator based
- RPC based

Performance simulations based
on realistic detector models,
backgournd estimates,
MC tuned to test beam data

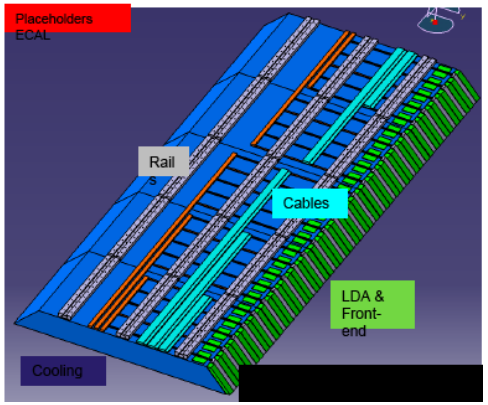


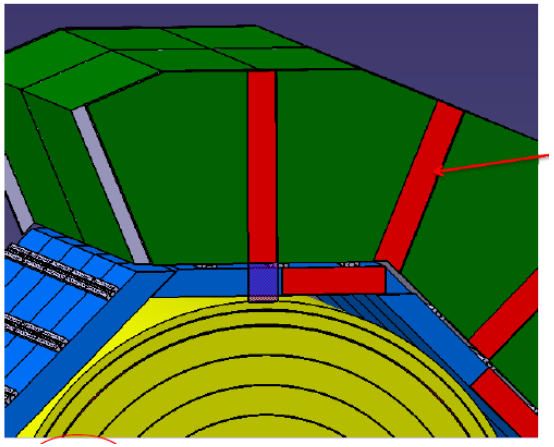
Detector Integration



ILD integration study.

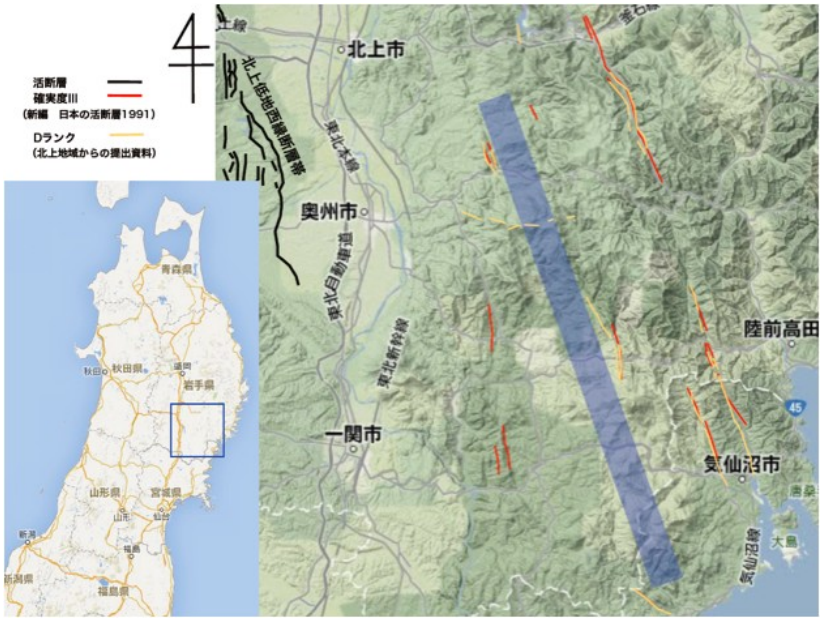
ILD simulation model





A detailed detector concept exists.
It has been simulated in detail.
Most technologies needed have been demonstrated.
A preliminary engineering has been done.

Northern Japanese Site



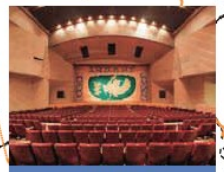
Geologically very stable area
Thinly populated, still well accessible
through major roads and high speed
rail roads
Closed big city: Sendai

Planned construction candidate site for the International linear collider and main surrounding facilities

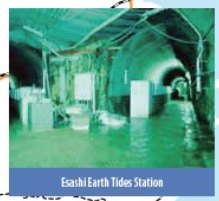
Oshu General Gymnasium

Lime-kun Farmer's Market

Ichinoseki National College of Technology


Ichinoseki Cultural Center

National Astronomical Observatory in Mizusawa Mizusawa VLBI Observatory


Esashi Earth Tides Station

Oshu
Kitakami
Ichinoseki
Hiraizumi
Kanegasaki
Tono
Kamaishi
Sumita
Ofunato
Rikuzentakata
Kesennuma
Miyagi Prefecture Kurihara
Miyagi Prefecture Tome
Miyagi Prefecture Kesennuma

International Linear Collider

A
B

This entire area is a prominent producer of a wide variety of agricultural products including high quality rice, beef, vegetables, and apples.

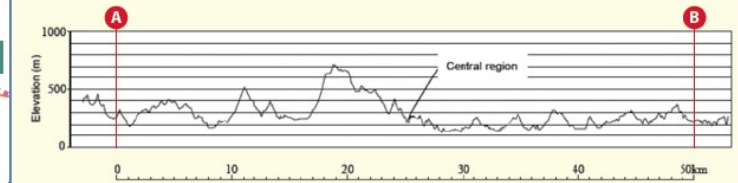
World Heritage HIRAIZUMI

Chusonji Temple

Motsuji Temple

Many temples, gardens, and ruins that were built based on the philosophies of Pureland Buddhism remain in excellent condition in Hiraizumi. The temples and gardens were an attempt to make an ideal world in our own reality. While receiving influence from abroad, it accomplished its own original development so that Hiraizumi expresses an ideal world the like of which can be found nowhere else.

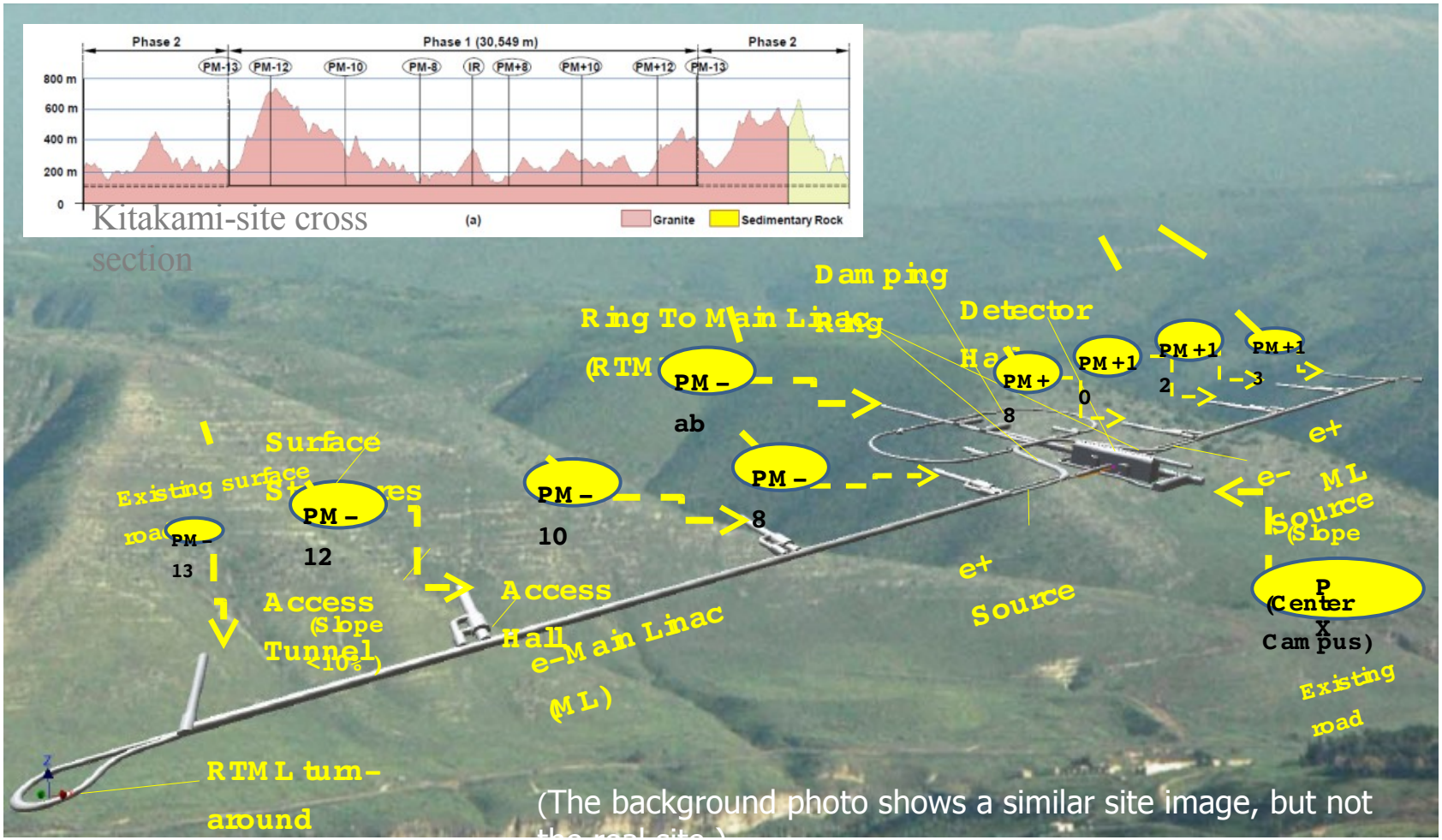
● Cross-sectional view of the ILC planned construction candidate site



http://www.city.oshu.iwate.jp/htm/ilc/archives/rayofhopee.pdf

2.7.2014

ILC siting



Need to establish the IP and linac orientation

Then the access points and IR infrastructure

Then linac length and timing

International Situation

EU: strong support for a Japanese initiative to host the linear collider

US: P5 process just finished
- strong support for the physics case of the ILC
- in any scenario ILC plays a role in the US
- for being a leading partner additional funding would be needed

Japan: MEXT has initiated internal study group
ILC has become an official project in Japan in MEXT
Detailed investigation is ongoing about the possibility to host
Budget for siting studies etc is being prepared
Official letters have been sent to US, and recently to Europe

Summary

A clear physics case exists for a lepton collider.

- Higgs physics
- Top physics
- BSM physics

If the 14TeV LHC finds nothing: we need to probe the Higgs boson and

the top quark with ILC precision

If the 14TeV LHC find new physics: this might make the case for an ILC even
stronger

The ILC design is mature and ready to go.

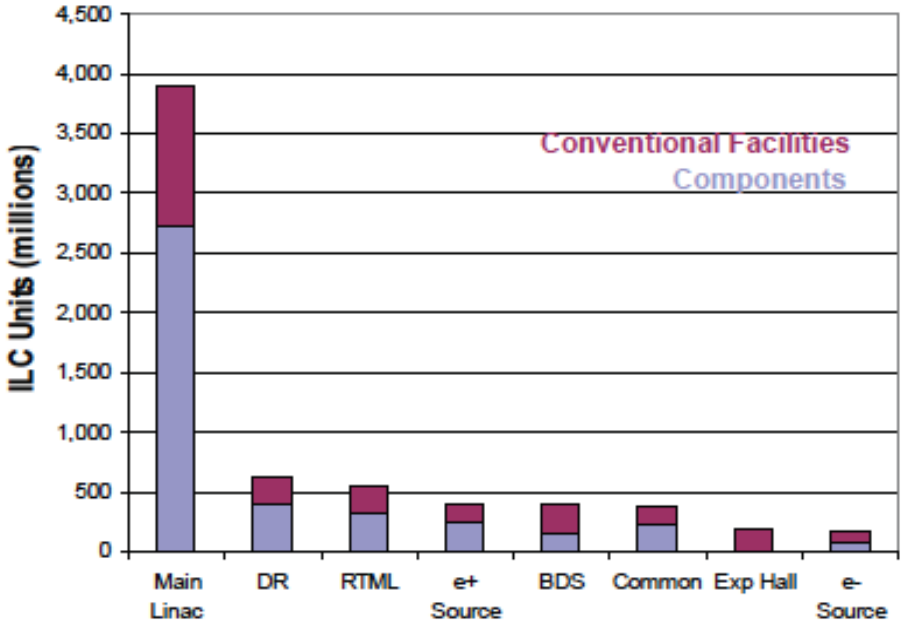
With the Japanese initiative we have a window of opportunity.

To learn more about ILD: www.ilcild.org, to signup to ILD: http://www-flc.desy.de/ild

©Rey.Hori/KEK

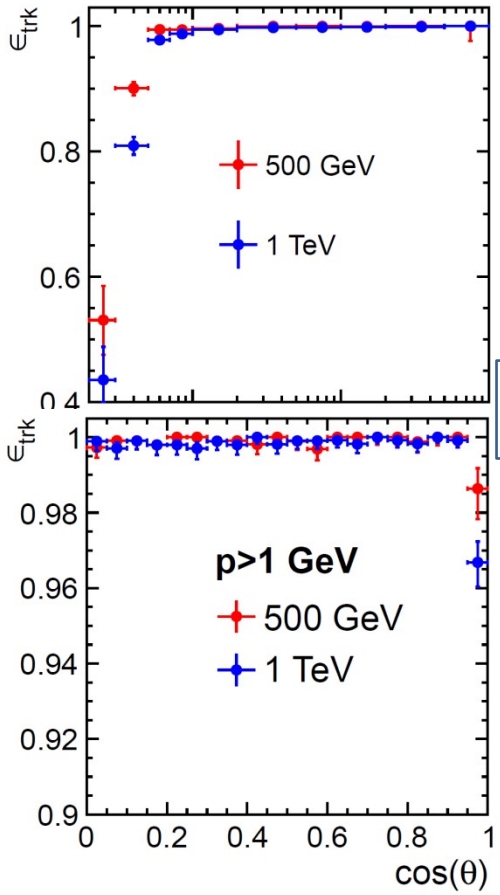
How much does it all cost?

- Estimate from 2007 Reference Design Report, escalated to 2012 prices:
  7.3 ☐ 109 $ + 14k years labor
- New estimate in 2013 Technical Design Report:
  7.8 ☐ 109 $ + 14k years labor (7% increase)
- Dominated by Main Linac

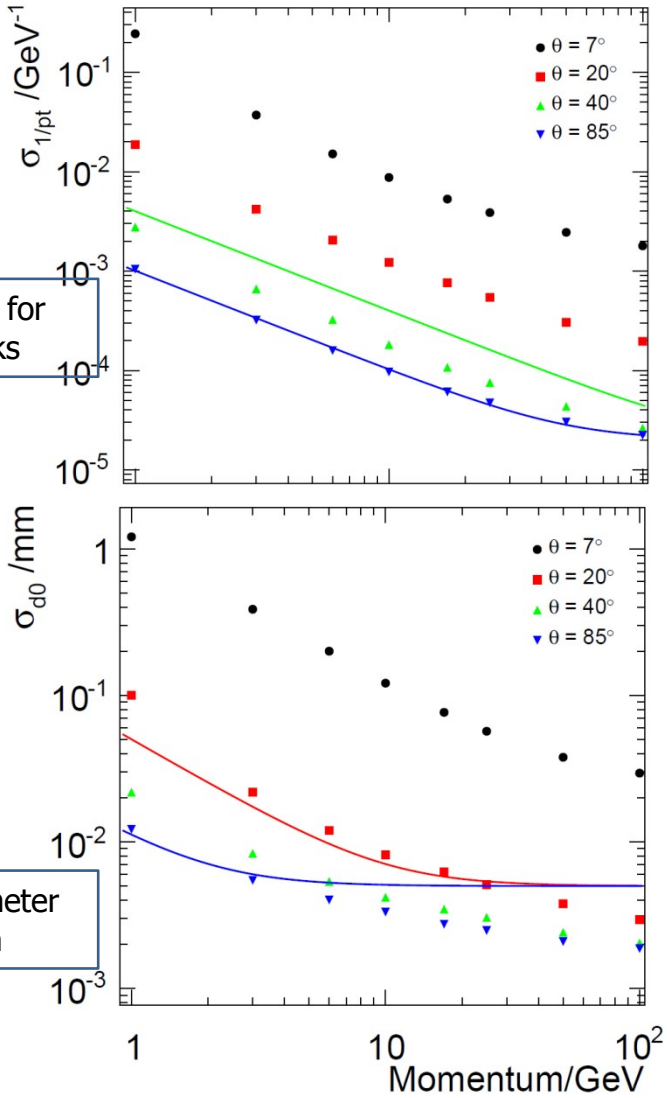


Tracking performance

- Performance goal
  - s1/pT~2x10-5GeV-1
  - srf=5⊕10/psin3/2q [um]



Tracking efficiency for t t events

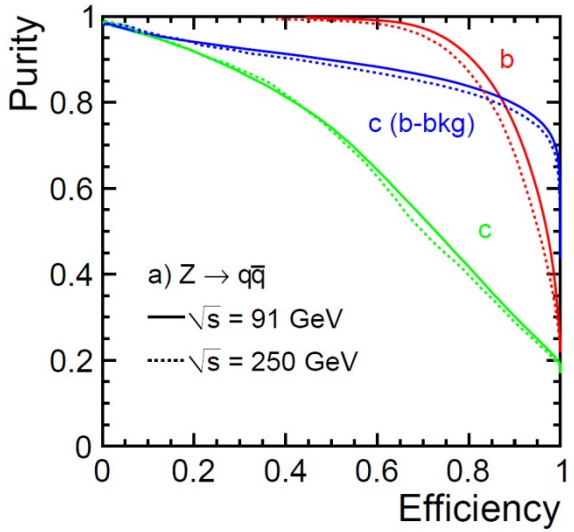


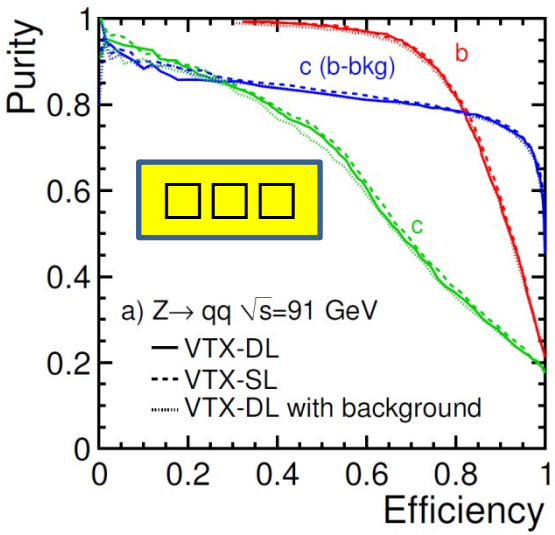
Pt resolution for muon tracks

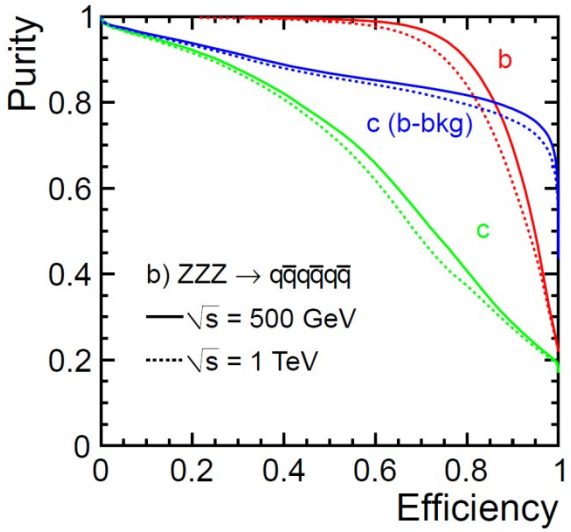
Impact parameter resolution

Flavor-tag performance

- Sophisticated multi-variable tagging algorithm (LCFIplus)
- Continuous improvement
- Based on full simulation.





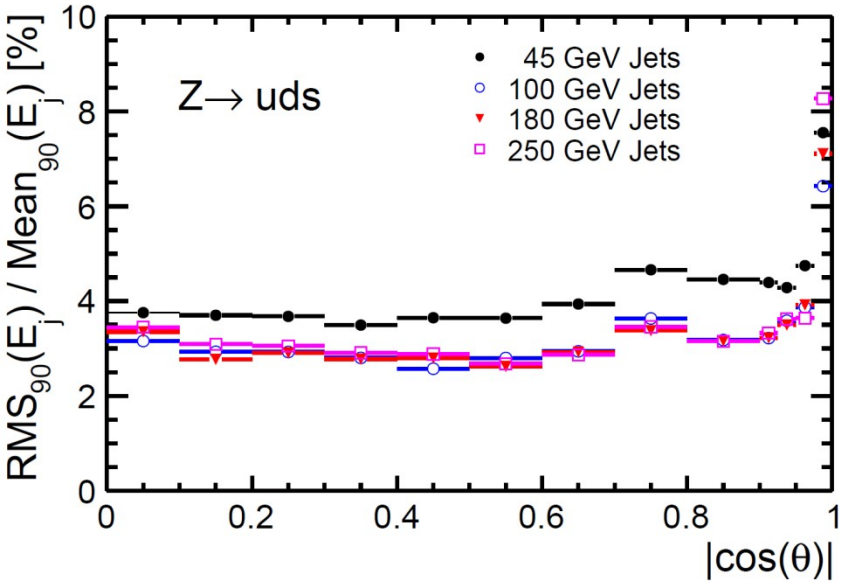


PFA performance

- Performance goal
  - Jet energy resolution < 3.5% for efficient separation of W, Z, and Higgs in hadronic mode
  - sE/E = a/sqrt(E) is not applicable because particle density depends on Ejet
  - Jet energy resolution is slightly better than LOI due to improvement of reconstruction software

Jet energy	σE/E
45 GeV	3.66%
100 GeV	2.83%
180 GeV	2.86%
250 GeV	2.95%

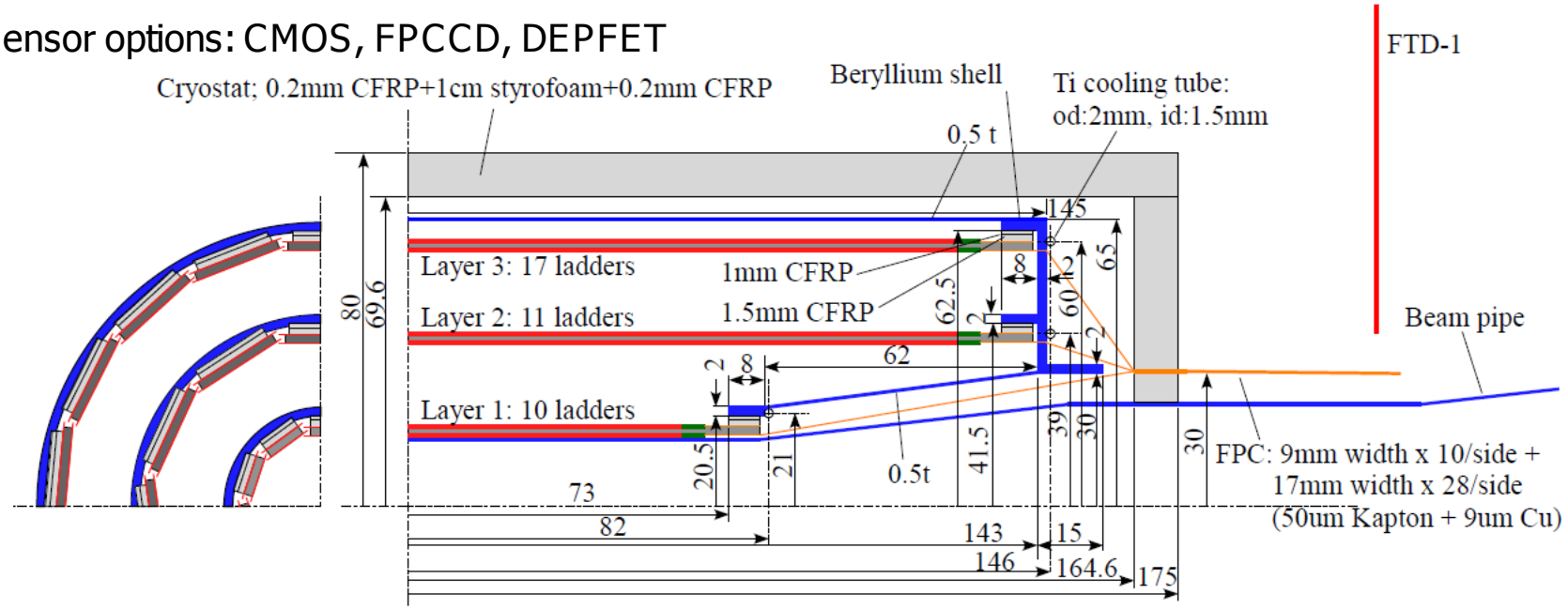
Z□u,d,s events
|cosθ|<0.7



Ties B ILD
2.7.2014

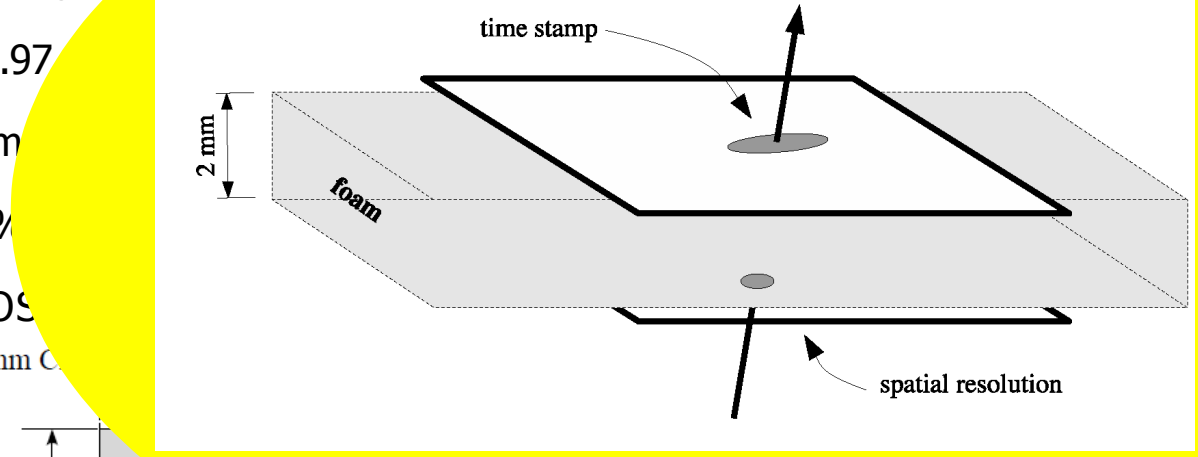
Vertex detector

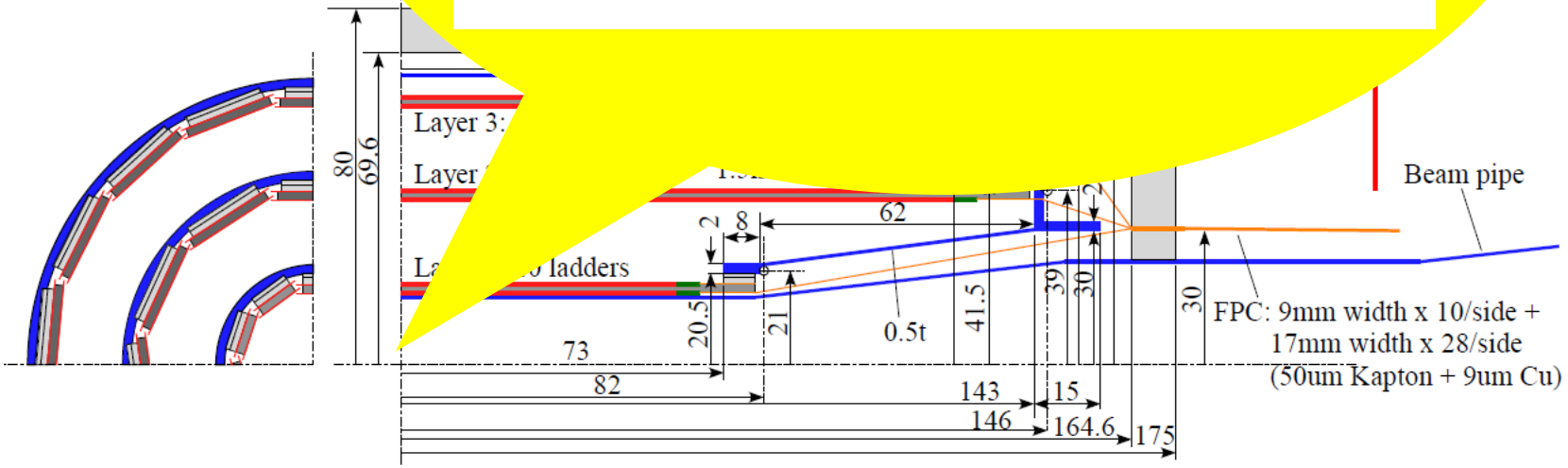
- Excellent impact parameter resolution better than 5⊕10/pbsin3/2q is required for efficient flavor tagging
- 3 layers of double ladders (ca 100 um apart) (6 pixel layers)
  - Effect on pair-background rejection is expected, but not demonstrated yet
- Barrel only: |cosq|<0.97 for inner layer and |cosq|<0.9 for outer layer
- Point resolution <3um for innermost layer
- Material budget: 0.3%X0/ladder=0.15%X0/layer
- Sensor options: CMOS, FPCCD, DEPFET



Vertex detector

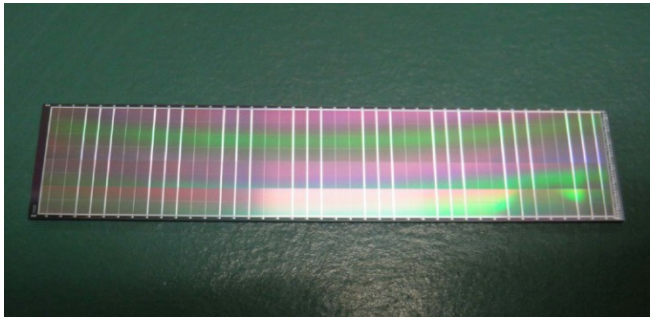
- Excellent impact parameter resolution better than 5⊕10/pbsin3/2q is required for efficient flavor tagging
- 3 layers of double ladders (ca 100
  - Effect on pair-backgrou
- Barrel only: |cosq|<0.97
- Point resolution <3um
- Material budget: 0.3%
- Sensor options: CMOS



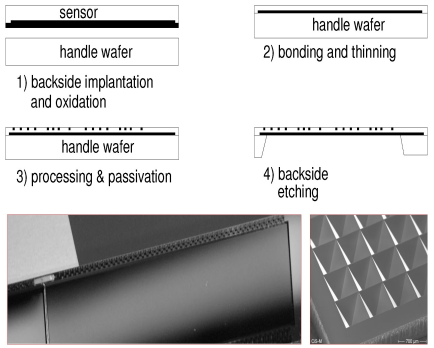


Vertex detector

- CMOS option
  - Pixel size: 17x17(L1), 17x85(L2), 34x34(L3-6)
  - Frame readout time: 10us~100us
  - Power consumption: 600W □10W by power pulsing
- FPCCD option
  - Pixel size: 5x5 (L1-2), 10x10(L3-6)
  - Readout between trains
  - Power consumption: ~40W (no power pulsing)
- DEPFET option
  - Experience at Belle-II
  - Frame readout time: 50us~100us
  - 5-single layer of all-Si ladder option
- Cooling
  - CO2 cooling for FPCCD
  - Additional material budget is small: 0.3%X0 in end-plate 0.1%X0 in cryostat
  - Air cooling for CMOS/DEPFET

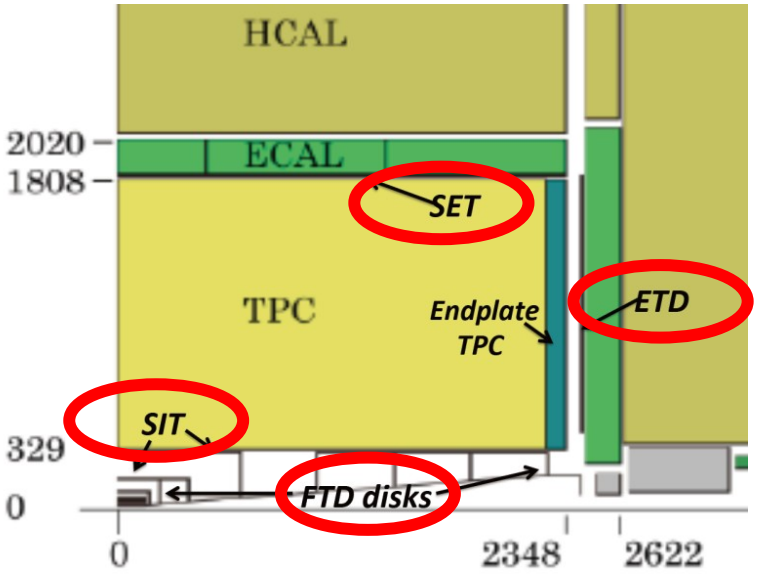


DEPFET all Si



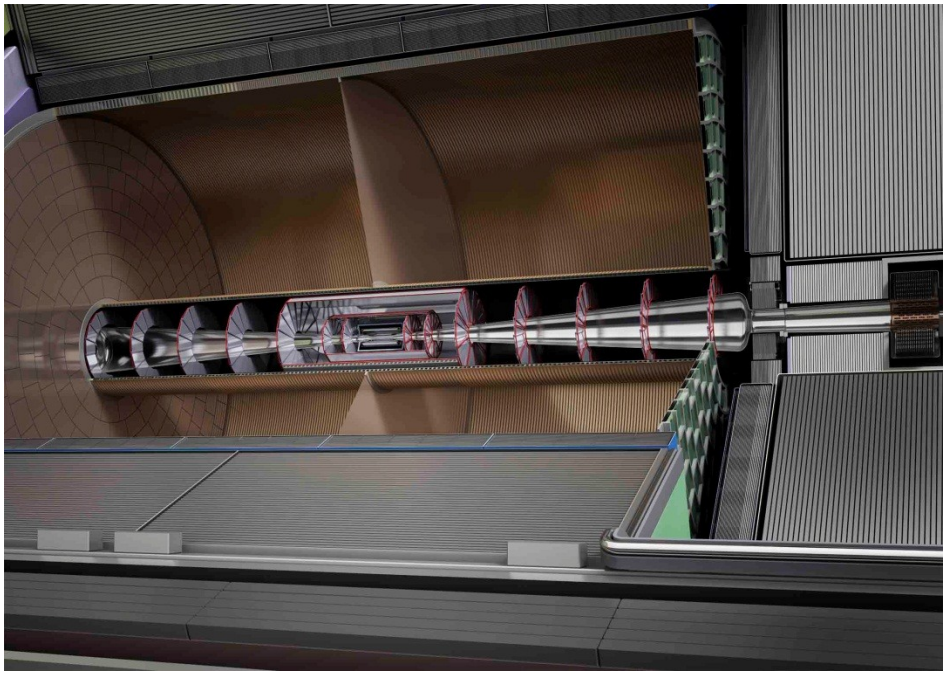
Silicon tracking system

- Silicon tracking system
  - SIT (Silicon Inner Tracker)
  - SET (Silicon External Tracker)
  - ETD (Endcap Tracking Detector)
  - FTD (Forward Tracking Detector)
- Role of Silicon tracking system
  - Additional precise space points
  - Improvement of forward coverage
  - Alignment of overall tracking system
  - Time stamping
- SIT/SET/ETD
  - Two/one/one false double-sided layers of Si strip
  - Material budget: 0.65%X0/layer
  - Same silicon strip tiles of 10cmx10cm with 50um pitch, 200um thick, edgeless sensors will be used
  - Point resolution of ~7um



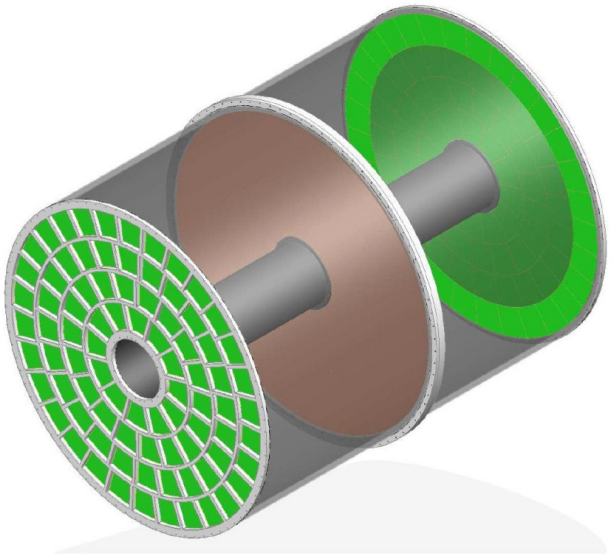
Forward Silicon tracking system

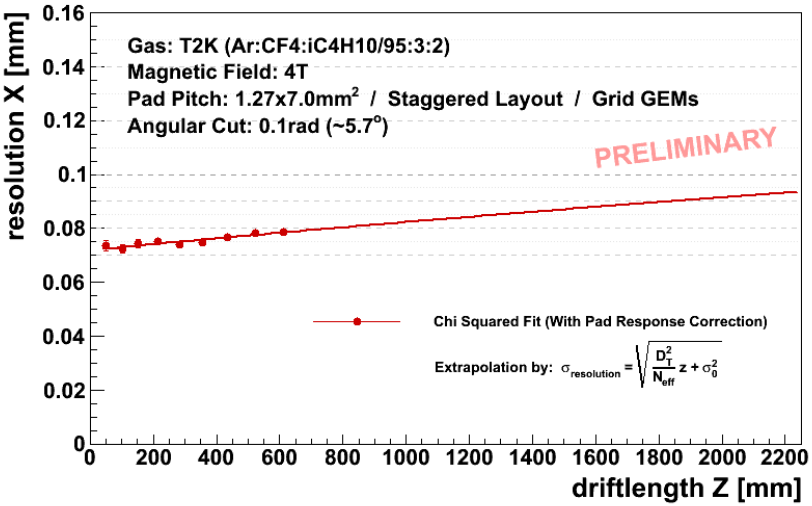
- FTD
  - Two pixel discs and five false double-sided strip disks
  - Pixel sensor options: CMOS, FPCCD, DEPFET
  - Power consumption: 2kW/disk ☐ 100W/disk by power pulsing



TPC

- Time Projection Chamber: The central tracker of ILD
- Tracks can be measured with many (~200/track) 3-dimensional r-f-z space points
- srf<100um is expected
- dE/dx information for particle identification
- Two main options for gas amplification: GEM or Micromegas
- Readout pad size ~ 1x6mm2 □106 pads/side
- Pixel readout R&D as a future alternative
- Material budget: 5%X0 in barrel region and <25%X0 in endplate region
- Cooling by 2-phase CO2





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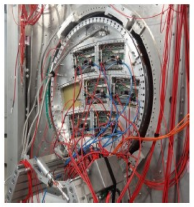
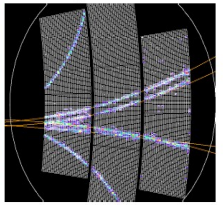
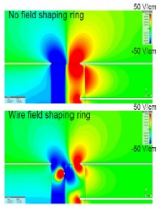
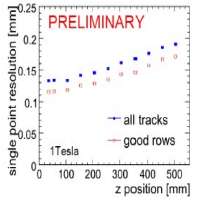
Multi-module setups with highly integrated electronics are tested in the LP:
For example the 6-module setup with MM+resistive layer modules in 7/2012.

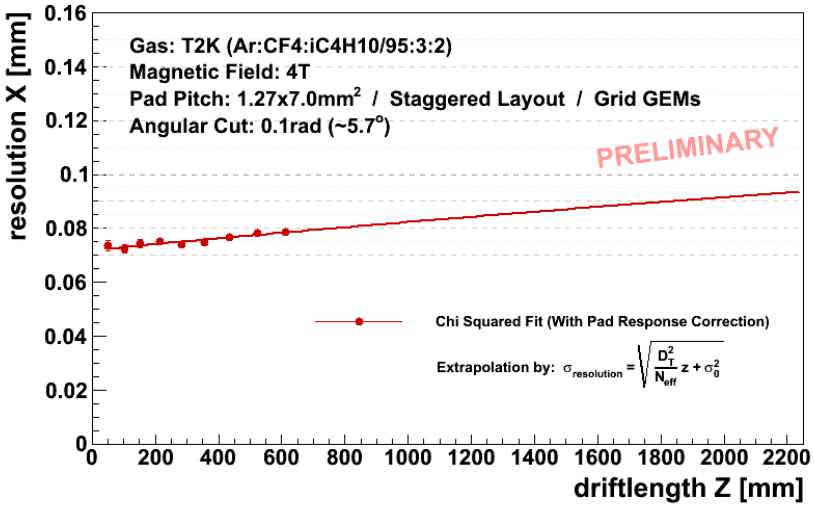






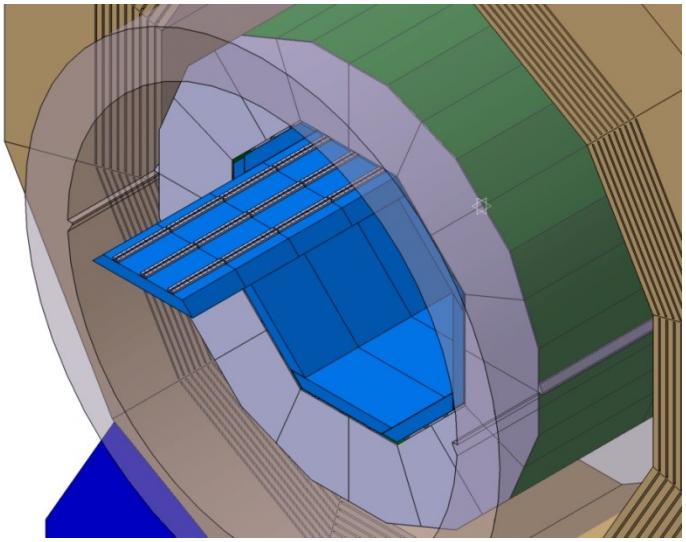
Field distortions at the border of the modules are seen with all gas amplification technologies (GEMs, MM, InGrids) and solutions are being investigated.

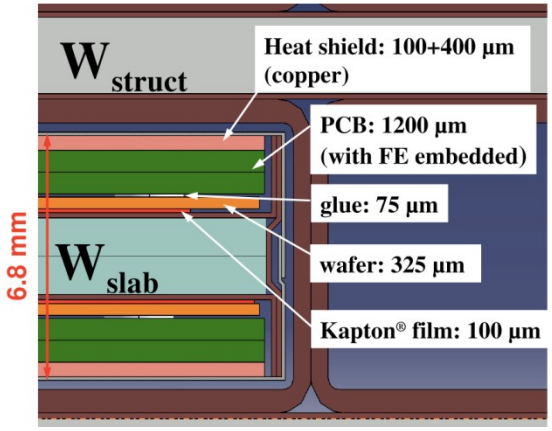


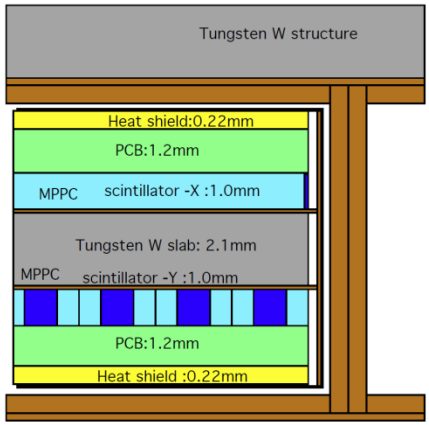


ECAL

- Sampling calorimeter of tungsten absorber / Si or scintillator-strip sensitive layer sandwich
- 30 layers / 24X0
- Si sensor: 5x5mm2 pixel size
- Scintillator strip: 5x45mm2, read out by MPPC
- Leak-less water cooling
- Detailed design exists, prototyped
- Discussions with industry are ongoing on production and costing.

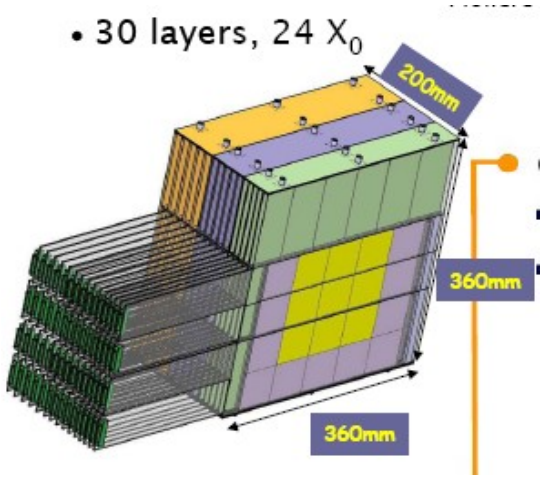




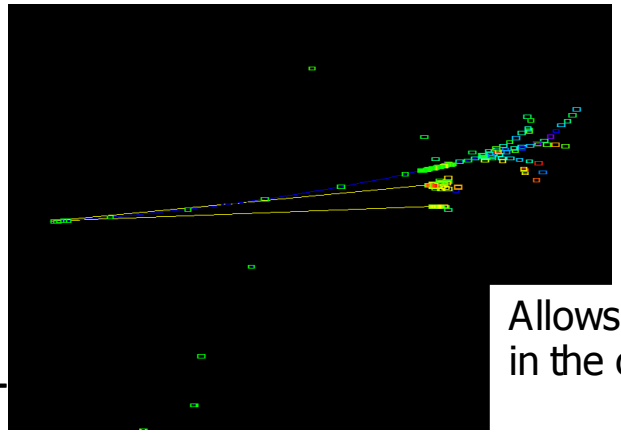


PFLOW ECAL

Typical granularity for ECAL: 0.5cmx0.5cm to 1cmx1cm,
SI detectors, Tungsten absorbers

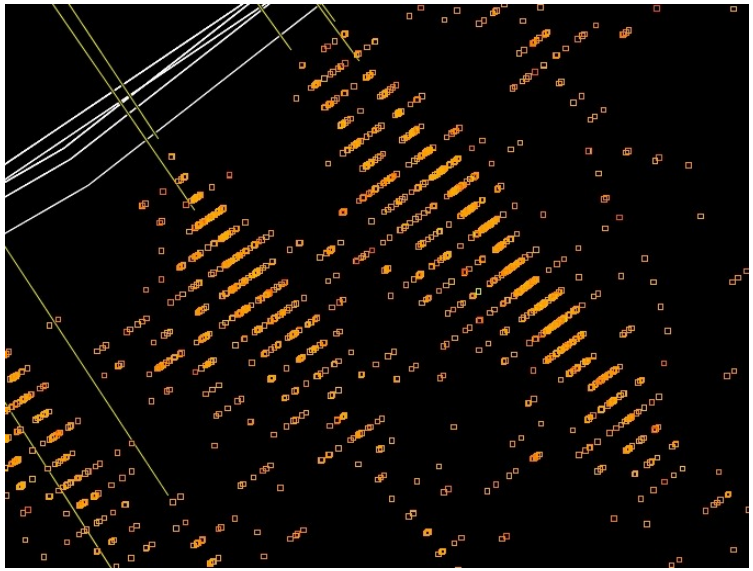


CALICE prototype



Allows "tracking" in the calorimeter

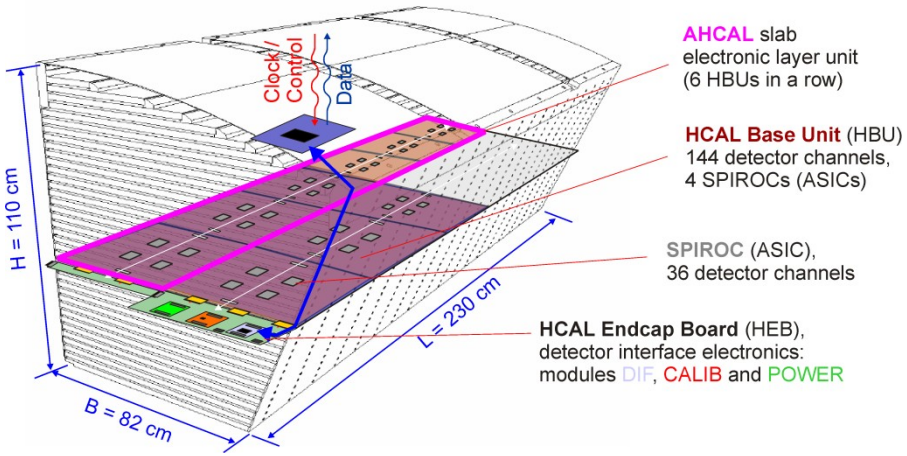
Extreme segmentation:
MAPS sensors in the ECAL

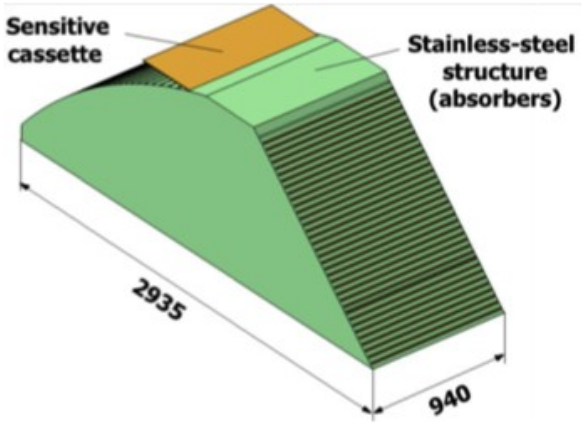


Very detailed shower images

HCAL

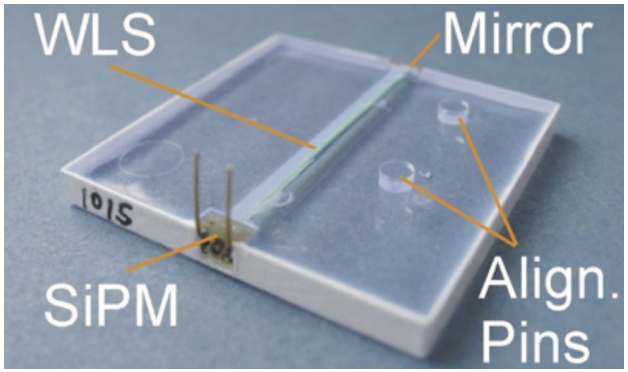
- Sampling calorimeter with steel absorber (48 layers, 6lI)
- Two options for the active layer
  - Scintillator tiles with analog readout ☐AHCAL
  - Glass RPC with semi digital (2-bits) readout ☐SDHCAL

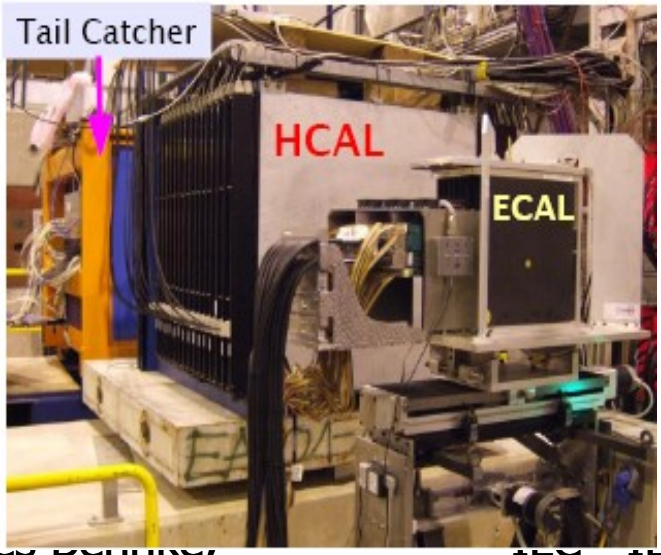


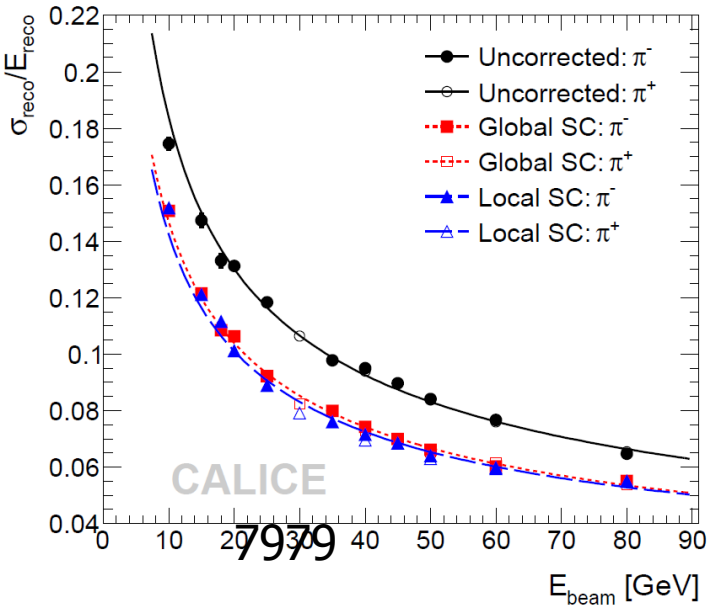


AHCAL

- 3x3cm2 segmentation of 3mm thick scintillator read out by SiPM through wavelength shifting fiber (Elimination of WLS under study)
- Software compensation (e/p ~1.2) technique was show to work well through beam tests: 58%/E1/2 □ 45%/E1/2
- Test beam results are also used for evaluation of GEANT4 physics list

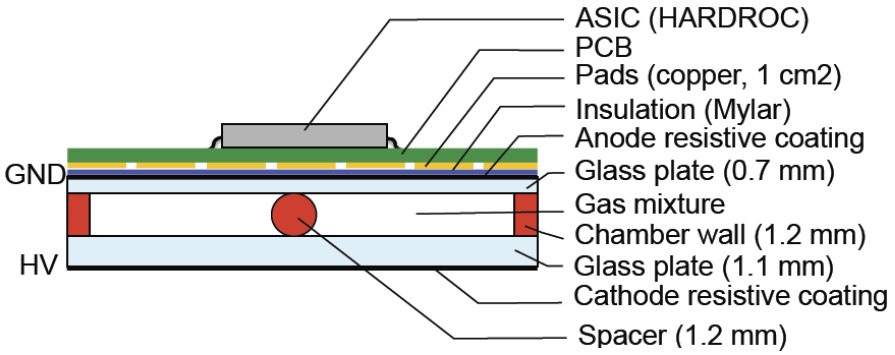


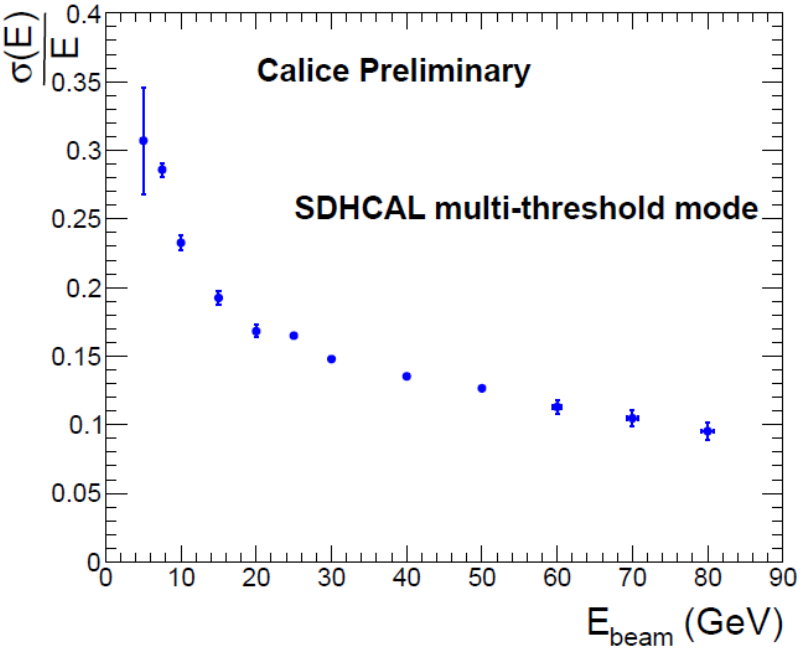


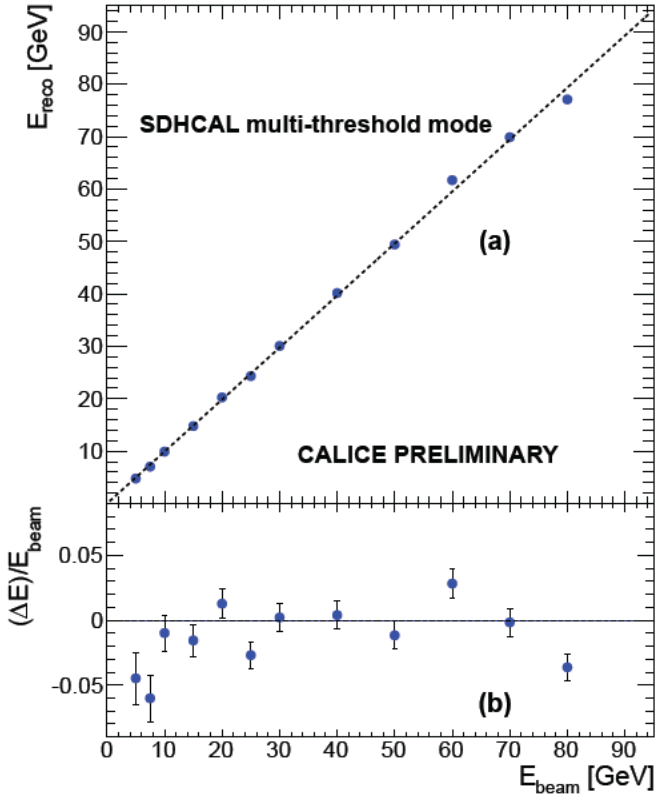


SDHCAL

- Active layer: GRPC with 1.2mm gap with 1x1cm2 signal pick-up pads
- Demonstrated to work with power-pulsing in 3T B-field
- Test beam at CERN PS and SPS

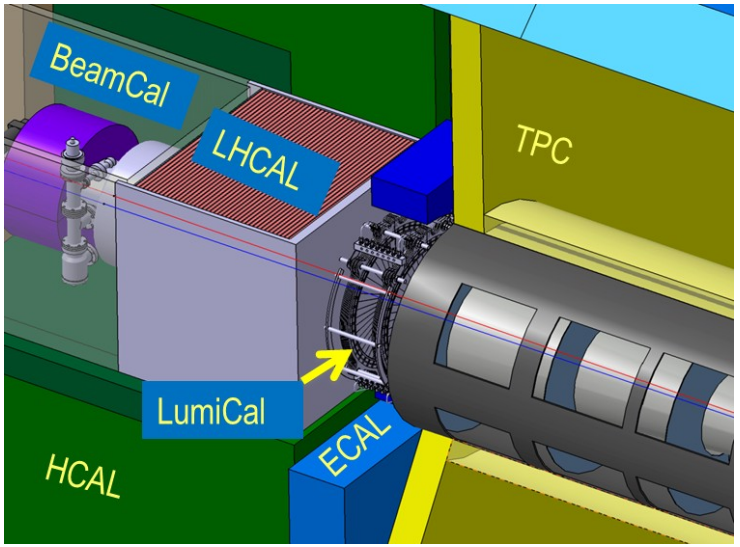






Forward calorimeters

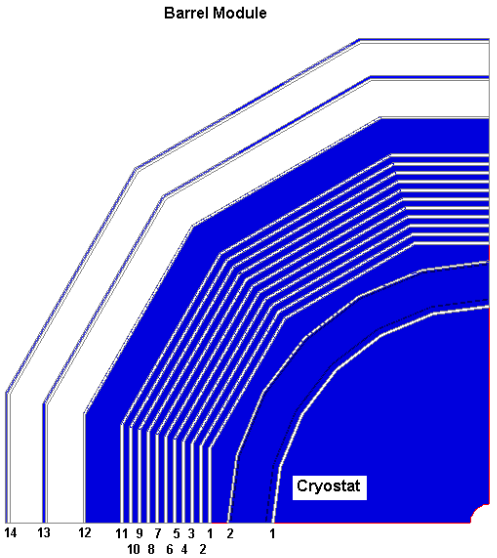
- LumiCal
  - Precise (<10-3) luminosity measurement
- BeamCal
  - Better hermeticity
  - Bunch-by-bunch luminosity and other beam parameter measurements (~10%)
- LHCAL
  - Better hermeticity for hadrons

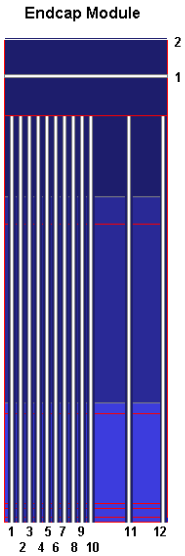


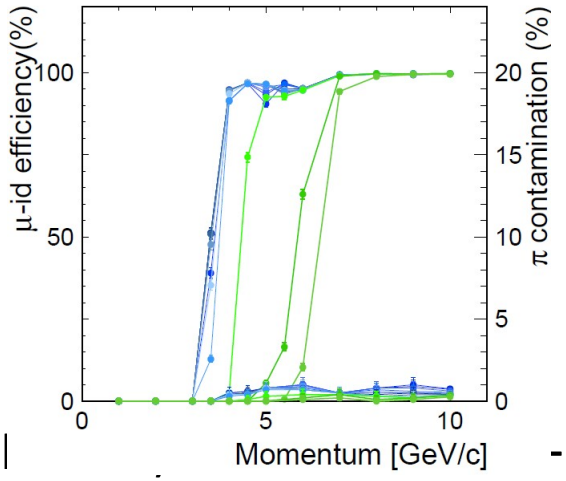
	Technology	Coverage
LumiCal	W-Si	31 – 77 mrad
LHCAL	W-Si	
BeamCal	W-GaAs / Diamond	5 – 40 mrad

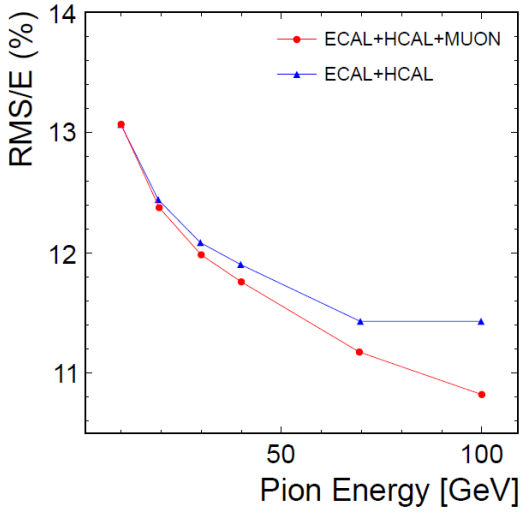
Muon system

- Active layers (14 for barrel, 12 for endcap) interleaved with iron slabs of return yoke
- Baseline design adopts scintillator strips + WLS fiber + SiPM readout as the active layer
- RPC is considered as an alternative
- Used for muon identification and as a tail catcher of the HCAL



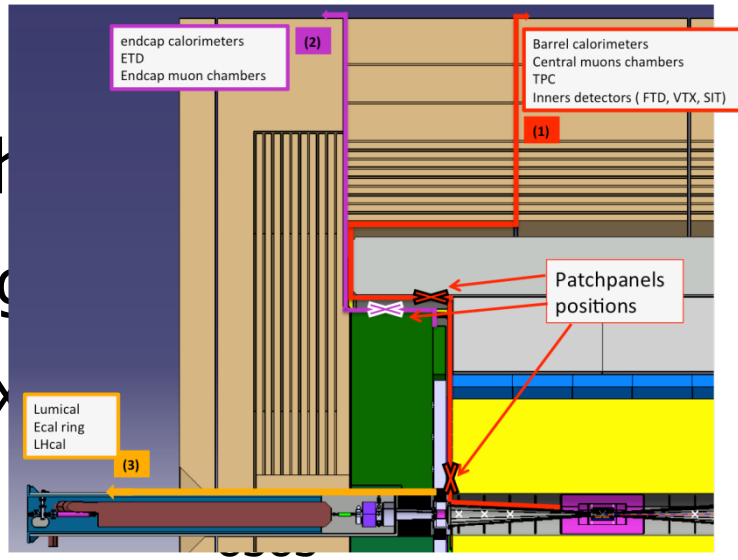






Detector integration

- Detector assembly
  - Non-mountain site: CMS style
    - Pre-assembled and tested on surface
    - Large pieces (3 barrel rings + 2 endcaps) are lowered through vertical shaft
      - 3500t crane for the vertical shaft
      - Yoke rings are assembled underg
      - 250t crane in the underground ex
  - Barrel detectors
    - services go through gap of
- Detector service path
  - Mountain site: Access through h
  - Detector services (cables and tubes) are considered seriously for ILD



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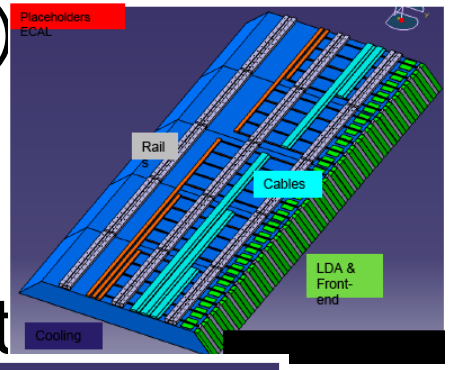
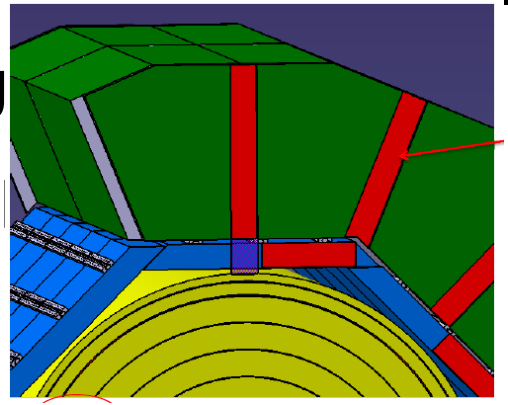
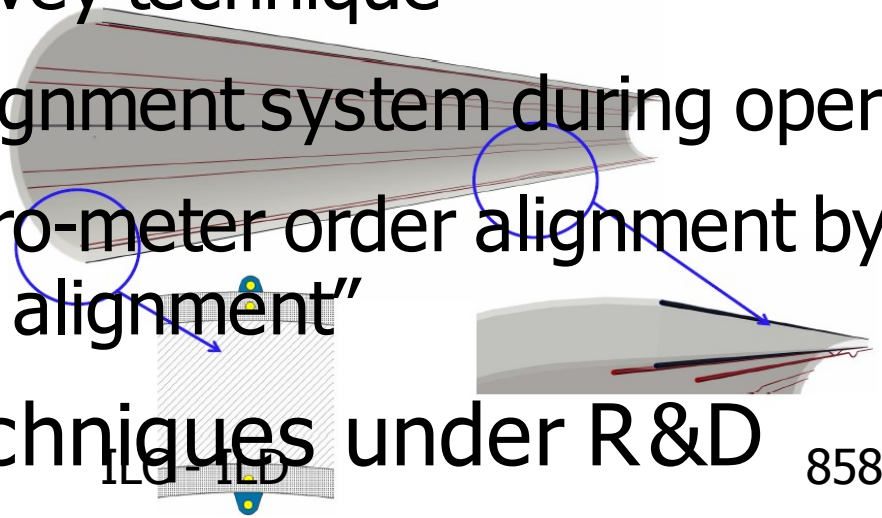




- Detector service path
  - Mountain site: Access through horizont
  - Detector services (cables and tubes) are considered seriously for ILD

Calibration/Alignment

- Alignment procedure
  - Accurate positioning during construction of sub-detectors by coordinate measuring machine
  - Alignment at the installation phase by standard survey technique
  - Hardware alignment system during operation
  - Ultimate micro-meter order alignment by "track-based alignment"
- Alignment techniques under R&D